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Authors

VanderWerf, Joel
Shladover, Steven
Miller, Mark A.

Publication Date

2004-08-01

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Joel VanderWerf
Steven Shladover
Mark A. Miller

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

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Joel VanderWerf

Steven Shladover

Mark A. Miller

Final Report for Task Order 4230

May 31, 2004

ACKNOWLEDGEMENTS

ABSTRACT

This report documents work for Task Order 4230 that was follow-on work to prior research performed at PATH under Task Order 366. The current work continued to expand our understanding of the issues involved with time-staging the deployment of advanced vehicle control and safety systems (AVCSS) to help lead toward future automated highway systems. The time-staging challenge has long been identified as one of the most significant impediments to deployment, particularly because of the "chicken and egg" problem associated with vehicle and infrastructure technology implementation. These "chicken and egg" deployment challenges are also being investigated on an international scale. As part of this project we also conducted a detailed review of the international status of AVCSS development and deployment, in collaboration with the European Commission's STARDUST project and provides a comprehensive picture of the status of these technologies not only in the U.S., but also in Japan and Europe. In terms of the time-staging aspects of AVCSS deployment, heavy vehicle opportunities are likely to develop earliest, however, the largest potential benefits are still likely when the technologies are applied to the much larger population of passenger cars.

Key Words: Advanced vehicle control and safety systems, modeling and simulation, autonomous and cooperative adaptive cruise control, automated buses, automated trucks, deployment staging of automation

EXECUTIVE SUMMARY

This report documents work for Task Order 4230 that was follow-on work to prior research performed at PATH under Task Order 366 — "Development and Performance Evaluation of AVCSS Deployment Sequences to Advance from Today's Driving Environment to Full Automation", that began to address these issues. In this earlier work, we investigated deployment staging leading to automated highway systems by modeling the effects of driver control assistance systems relative to human driving, including both autonomous and cooperative adaptive cruise control systems, evaluated the effects of such systems on highway traffic flow capacity, and examined institutional issues. That project also served as a precursor to the testing and demonstration of automation technologies for heavy-duty vehicles at Demo 2003.

The research performed in the current project focused on three areas of investigation:

1. Evaluation of the effects of driver control assistance systems relative to human driving for the *multilane highway case* with light duty passenger vehicles
2. Conceptual development for similar and eventual modeling and evaluation of *trucks and buses*
3. Review of the state of international research (including simulation and evaluation) and technology demonstrations of vehicle-highway automation systems.

These three tasks helped fill gaps in knowledge about deployment staging toward cooperative vehicle-highway automated systems and provided a more complete picture at Demo 2003.

There was a two-phase approach taken during this project. First, in the study of the multi-lane case for evaluating the highway capacity impacts of manual driving, AACC, and CACC, we utilized a quantitative approach based on and similar to the work we used previously, that is, we used the simulation models that were developed, validated, and previously used to evaluate the impacts in the single lane case. Secondly, the conceptual framework development for truck- and bus-based vehicle highway automation systems and the assessment of the international state of research and deployment for vehicle-highway automation systems were determined primarily through a review of the research literature, an assessment of vehicle-highway automation demonstrations both recently completed and planned for, and discussions with experts in the field.

Evaluation of the Effects of Driver Control Assistance Systems Relative to Human Driving

Opportunities for deployment are likely to develop earliest for heavy-duty vehicles, i.e., trucks and buses, however, the largest potential benefits are still likely when the technologies are applied to the much larger population of passenger cars. The first stage in passenger car implementations that could provide benefits beyond the comfort and convenience of adaptive cruise control (ACC) is likely to be cooperative ACC (CACC). A detailed modeling approach for predicting the highway capacity benefits of CACC was performed, but the benefits have only been predicted for a single-lane example because of the complexities of modeling lane changing behavior in multi-lane driving environments. The lane capacity benefits of CACC are potentially so substantial that this requires further research, specifically to narrow down the remaining uncertainties about the underlying assumptions in the CACC analysis. The key issue

to be addressed there is determining how willing drivers will be to operate their cars closer together when they have high-performance CACC available.

For the single lane case, we used simulation to predict the effect of adaptive cruise control (ACC) systems on traffic flow in a single lane highway. We considered three control types: manual control, autonomous ACC (AACC), and cooperative ACC (CACC) with vehicle-to-vehicle communication. The roadway chosen for study was the area around a merge point. The merge was intended to inject realistic disturbances into the main traffic stream. We modeled merging somewhat abstractly as gap acceptance followed by insertion at the speed of traffic. Upstream traffic was generated using exponentially distributed inter-arrival times. Vehicles and drivers took their characteristics from a set of distributions with some empirical basis. Vehicles entered and exited the roadway using an algorithm designed to minimize the boundary effects. We estimated capacity by varying the rate at which vehicles were generated and queued (off-road) to enter at the upstream entrance or at the merge point; overflow of these virtual queues indicated that demand had exceeded capacity. We estimated capacity for a range of market penetration ratios for the three control types.

For time gap settings of 1.55, and 1.4, the AACC capacity curves peak at approximately 20% and 40% market penetration, respectively. For these two time gap settings, a mixture of AACC vehicles with manually driven vehicles improves flow because they tend to smooth out disturbances. The decrease, especially above 40% for the time gap setting of 1.55 seconds and above 60% for the time gap setting of 1.4 seconds, occurs because the time gap setting of the AACC is larger than the mean desired time gap for manual driving, which is 1.1 seconds. Without manual drivers (in the 100% AACC case), little additional advantage is gained by the smoothing effect, and the longer time gap settings (1.55 and 2.0 seconds) actually reduce flow. For the time gap setting of 1.0 second, flow improves for all AACC market penetration values since the presence of AACC vehicles helps smooth out disturbances and the time gap setting is less than the mean desired time gap for manual driving.

These results clearly show the profound importance that the driver selection of time gap setting has on the highway capacity that can be achieved with ACC systems at high market penetrations. At full market penetration, the effect of ACC could range from a substantial capacity decrease to a substantial capacity increase. However, if drivers gravitate toward the middle time gap settings, or choose the longest and shortest time gaps in similar numbers, the effects on highway capacity are likely to be negligible. Similarly, regardless of the time gap settings selected, the effects on capacity of an ACC market penetration of 20% appear to be negligible.

In the multi-lane phase of the project, we extended and adapted our software into a simulation framework that can be used to predict the capacity effects of the different vehicle control classes in a more general multi-lane setting and with the increased realism of an explicitly modeled merge lane. Merging and lane changing is still under manual control for all vehicle types, because the technology that would be needed for implementing automated merging or lane changing is different from the ACC technology and is not likely to be available for public use for a long time. Some of the necessary inputs for applying the software to make confident predictions about highway capacity are still missing, however. We need more realistic driver model parameters for merging and lane changing behavior, and we need models that are sensitive to a particular driver's history of decisions from moment to moment. We did not obtain such parameter values to our satisfaction either by deriving them from existing literature or by tuning

our simulation so that macroscopic measurements of flow and lane changes matched observational data. Nevertheless, the software developed in this project is valuable in itself. It has already been used to generate traffic traces for input into a wireless networking simulation, discussed below, and parts of it are being reused in several other ongoing projects.

Development of Vehicle-Highway Automation System Concepts for Trucks and Buses

It appears most likely that earliest deployments of AVCSS technologies will be on heavy vehicles operating on their own special rights of way for a variety of reasons:
- Easier to develop and acquire rights of way for public purposes (transit service, getting trucks off mixed-traffic roads)
- Maturing technologies can be used more safely by professional drivers on professionally maintained vehicles than by the general public on vehicles that may not be maintained at all
- Costs of the technologies are a smaller percentage of total vehicle costs and vehicles are used much more intensively than private automobiles, so these costs are amortized much faster
- Benefits in travel-time reduction, trip reliability and safety can be translated more directly into cost savings than for private cars
- Customized, small-lot production of vehicles makes it possible to introduce AVCSS technologies into the production process faster than for automotive mass production
- Packaging of new technological elements is easier on larger vehicles
- Heavy vehicles already have more onboard electronic infrastructure to use as a foundation for more advanced capabilities than passenger cars

The basic principles of earliest deployments of the more advanced technologies in transit buses and heavy trucks appear to apply similarly across the countries because of similar economic circumstances and expected benefits. The deployments must in each case be based on the ability of the technologies to solve significant transportation problems, because the technology-push model of a "solution looking for a problem" is not generally viable. The transportation industries and agencies whose problems could be solved by AVCSS technologies are not necessarily aware of these opportunities, and need to be educated more effectively about the possibilities than they have been heretofore. The beneficiaries of bus automation cover the transit properties, bus drivers, bus passengers, and infrastructure owners and operators. The beneficiaries of truck automation include commercial vehicle operators, truck drivers, infrastructure owners and operators, and the general public. The benefits of truck automation are somewhat different from those for transit bus automation, based largely on the differences between the operating characteristics and normal uses of buses and trucks, however, overall the benefit for both bus and truck automation will be an improved level of people movement, mobility, and quality of service. Detailed quantification of those benefits will have to depend on case studies addressing site-specific transportation problems and the ways in which AVCSS technologies can help in solving them.

Review of the State of International Research and Technology Demonstrations of Vehicle-Highway Automation Systems

Advanced Vehicle Control and Systems (AVCSS) are being rapidly developed in North America by vehicle manufacturers and others. These are products, for which there is a market, that are intended to provide additional safety and comfort to drivers. In addition, new highway

infrastructure may enable such systems and related services to operate more effectively against broader criteria such as efficiency of operation or the environment. The research and development of Advanced Driver Assistance Systems (ADAS)/Automated Vehicle Guidance (AVG) systems in Europe are being implemented at three levels: industrial, national and European. At a European level, research from the PROMETHEUS and DRIVE research programs indicated the potential for driver assistance systems to improve safety, efficiency and minimize the environmental impacts of road traffic.

In the U.S., the main AVCSS program under the USDOT is the Intelligent Vehicle Initiative (IVI), which incorporated the NHTSA-OCAR program and has other elements to address safety of transit buses, heavy trucks and "specialty vehicles". The states that have shown particular interest in AVCSS activities have been California, Minnesota, Virginia and Arizona. PATH has already invested more than 550 person years of effort on AHS research and development. The states have started to join forces to work together on "multi-state pooled fund projects". Two such multi-state projects are particularly relevant: the "IVI Infrastructure Consortium" in which California, Minnesota and Virginia jointly work on the development of systems that can enhance safety by enhanced vehicle-infrastructure interactions; and the "Cooperative Vehicle-Highway Automation Systems (CVHAS) Pooled Fund Project" in which California and ten other states explore how to use cooperative vehicle-highway automation technology to help reduce traffic congestion.

In Japan, the main R&D programs on ADAS/AVG are the "Automated Highway System (AHS)", "Assist Highway System Research Association (AHSRA)" by the Ministry of Construction; and the "Advanced Safety Vehicle (ASV)" by Ministry of Transport. In 1996, the world's first driving tests on public roads were implemented, which demonstrated the viability of the technology. In 2000, Japan held a Proving Test and Public Demonstration for the "Smart Cruise Systems" scheduled to begin deployment by the year 2003. Also, actual deployment of Smartway, which will become the platform for AHS and other systems, will begin in approximately 2003. By the year 2015, Smartway will be deployed on all major roads in Japan.

Collision warning systems have been extensively prototyped and tested.   Night vision and backup warning systems are now available on some automobiles, and Mitsubishi and Nissan have announced the near-term availability of collision warning packages. Forward collision warning and lane departure warning are expected to become available in the next few years. The Japanese Smartway concept will implement user services such as lane keeping, intersection collision avoidance, pedestrian avoidance, and headway keeping. European Commission funding is also supporting research on longitudinal and lateral collision warning, and the US IVI program is establishing a partnership with key automotive manufacturers to perform pre-competitive research in the areas of human factors (driver workload), use of high accuracy digital map databases, and development of metrics and testing methodologies for collision warning/avoidance products.

The highest-profile driver assistance product at the moment is Adaptive Cruise Control (ACC), now available in Europe and Japan and soon to be introduced in the US. Current ACC systems are geared for highway speeds; the next-generation systems (now in testing) will also support 'stop-and-go,' congested conditions.   In 1999, Mitsubishi introduced its new Driver Support System in Japan, which supplements ACC with lane departure warning and side and rear monitoring via machine vision. Honda, Nissan and Toyota have developed several safety

subsystems within the joint Advanced Safety Vehicle project, including lane positioning, headway control, automatic braking, and obstacle warning.

Fully automated vehicle operation offers the advantages of safe travel, more efficient traffic flows, and convenience to the driver. This capability has been prototyped and demonstrated extensively during the nineties, thereby establishing technical feasibility. Current research focuses on refining system approaches. For the nearer term, Low Speed Automation (LSA) is expected to be very popular as a convenience item. LSA systems would be engaged in slow-speed congested traffic conditions, so that the driver can relax instead of controlling the vehicle under these tedious conditions. When the congestion clears and speeds increase, the driver would resume control. This capability is being developed in both Asia and Europe.

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1.0 PROJECT OVERVIEW

One of the most serious challenges to the credibility of vehicle highway automation as a potential solution to transportation problems has been the lack of convincing deployment strategies. Such strategies are needed to show how to advance, step by step, from today's transportation system with manually-controlled vehicles to a future system that includes fully automated vehicles. Considerable research attention has been devoted to defining the architecture and operating protocols, as well as the technology, of automated highway systems, however, less attention has been devoted to defining the steps by which we can get there.

This project served as a follow-on to PATH Project MOU 366 — "Development and Performance Evaluation of AVCSS Deployment Sequences to Advance from Today's Driving Environment to Full Automation", that began to address these issues. In this earlier work, we investigated deployment staging leading to automated highway systems by modeling the effects of driver control assistance systems relative to human driving, including both autonomous and cooperative adaptive cruise control systems, evaluated the effects of such systems on highway traffic flow capacity, and examined institutional issues. That project also served as a precursor to the testing and demonstration of automation technologies for heavy-duty vehicles at Demo 2003.

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2.0   MULTI-LANE MODELING AND SIMULATION OF TRAFFIC EFFECTS OF AUTONOMOUS AND COOPERATIVE ADAPTIVE CRUISE CONTROL

2.1   Summary of Previous Work

2.1.1   Single Lane Results

In References 2-1, 2-2, and 2-3 we used simulation to predict the effect of adaptive cruise control (ACC) systems on traffic flow in a single lane highway. We considered three control types: manual control, autonomous ACC (AACC), and cooperative ACC (CACC) with vehicle-to-vehicle communication. The roadway chosen for study was the area around a merge point. The merge was intended to inject realistic disturbances into the main traffic stream. We modeled merging somewhat abstractly as gap acceptance followed by insertion at the speed of traffic. Gap acceptance probability was based on research from (2-4). Upstream traffic was generated using exponentially distributed inter-arrival times. Vehicles and drivers took their characteristics from a set of distributions with some empirical basis. Vehicles entered and exited the roadway using an algorithm designed to minimize the boundary effects. We estimated capacity by varying the rate at which vehicles were generated and queued (off-road) to enter at the upstream entrance or at the merge point; overflow of these virtual queues indicated that demand had exceeded capacity. We estimated capacity for a range of market penetration ratios for the three control types.

2.1.2   Additional Results for Single Lane Case

This section describes some additional single-lane results that were not reported in (2-3). In these simulations, we restricted the population to manually driven and AACC-equipped vehicles. We varied the time gap setting and the market penetration of the AACC vehicles, as shown in Figure 1.
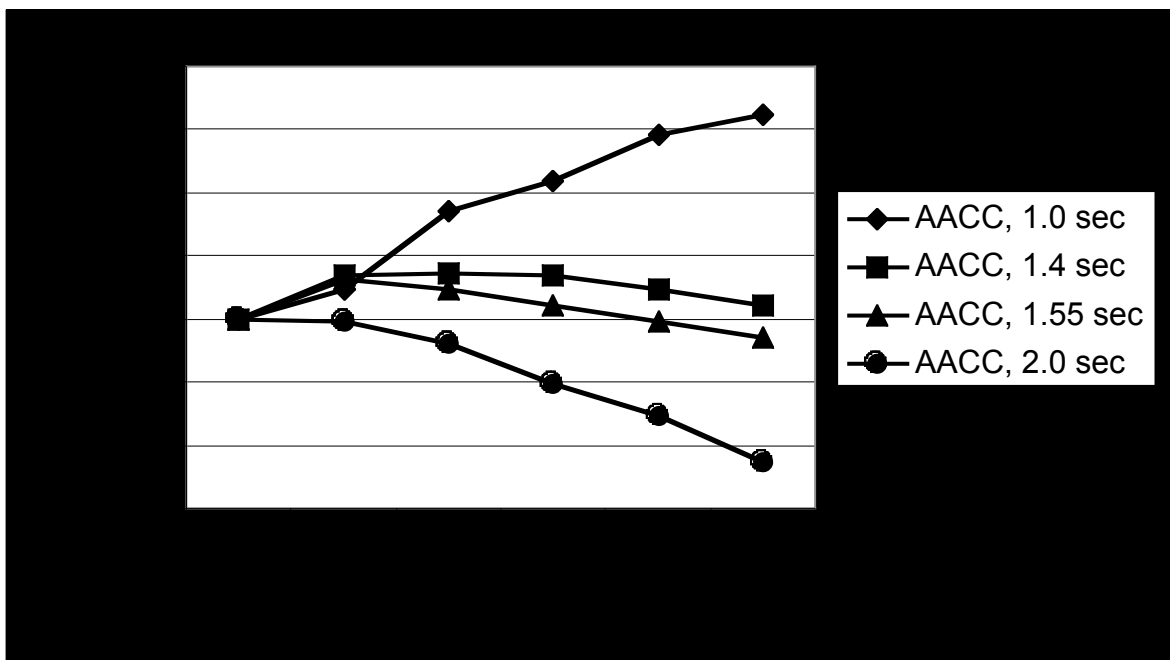

FIGURE 1 Effect on Lane Capacity of Increasing Proportion of AACC Vehicles with No CACC Vehicles.

For time gap settings of 1.55, and 1.4, the AACC capacity curves peak at approximately 20% and 40% market penetration, respectively. For these two time gap settings, a mixture of AACC vehicles with manually driven vehicles improves flow because they tend to smooth out disturbances. The decrease, especially above 40% for the time gap setting of 1.55 seconds and above 60% for the time gap setting of 1.4 seconds, occurs because the time gap setting of the AACC is larger than the mean desired time gap for manual driving, which is 1.1 seconds. Without manual drivers (in the 100% AACC case), little additional advantage is gained by the smoothing effect, and the longer time gap settings (1.55 and 2.0 seconds) actually reduce flow. For the time gap setting of 1.0 second, flow improves for all AACC market penetration values since the presence of AACC vehicles helps smooth out disturbances and the time gap setting is less than the mean desired time gap for manual driving.

These results clearly show the profound importance that the driver selection of time gap setting has on the highway capacity that can be achieved with ACC systems at high market penetrations. At full market penetration, the effect of ACC could range from a substantial capacity decrease (if all drivers choose the longest time gap) to a substantial capacity increase (if all drivers choose the shortest time gap). However, if drivers gravitate toward the middle time gap settings, or choose the longest and shortest time gaps in similar numbers, the effects on highway capacity are likely to be negligible. Similarly, regardless of the time gap settings selected, the effects on capacity of an ACC market penetration of 20% appear to be negligible.

2.2   Summary of Multi-Lane Studies

In the current phase of the project, we extended and adapted our software into a simulation framework that can be used to predict the capacity effects of the different vehicle control classes in a more general multi-lane setting and with the increased realism of an explicitly modeled merge lane. Merging and lane changing is still under manual control for all vehicle types, because the technology that would be needed for implementing automated merging or lane changing is different from the ACC technology and is not likely to be available for public use for a long time. Details of models, simulation experiment design, and software implementation are discussed in the following sections of this chapter.

Some of the necessary inputs for applying the software to make confident predictions about highway capacity are still missing, however. We need more realistic driver model parameters for merging and lane changing behavior, and we need models that are sensitive to a particular driver's history of decisions from moment to moment. We did not obtain such parameter values to our satisfaction either by deriving them from existing literature or by tuning our simulation so that macroscopic measurements of flow and lane changes matched observational data.

Nevertheless, the software developed in this project is valuable in itself. It has already been used to generate traffic traces for input into a wireless networking simulation, discussed below, and parts of it are being reused in several other ongoing projects.

2.3   Literature Review

As focus shifted from a single lane highway to a multi-lane highway, we needed to model drivers' selection and execution of lane change and merge maneuvers. At the time, the best work we were able to find on the subject was the dissertation of K. Ahmed (2-4). Unfortunately, we

found that the model, although detailed and apparently well founded on observations, was not quite suited to our purposes.

2.3.1 Lateral Control Model
The model presented in (2-4) is probabilistic in nature, rather than cognitive. This approach has the advantage of making parameter estimation relatively easy, though the resulting model reveals little about the processes of human perception and cognition. The primary limitation of this model is that it does not offer any grounds for predicting a sequence of related lane-change decisions. In fact, because the data was gathered from individual observations at a fixed location, rather than observations that followed a driver through a sequence of decisions, the data cannot support a model that makes such predictions. However, we do make use of the formulas for gap acceptance, because we have no better source of data.

2.3.2 Recent Evolution of the Model
In (2-5), which appeared too late to be incorporated into our modeling efforts, the model of (2-4) is significantly improved upon in one respect. Drivers may consider mandatory lane changes and discretionary lane changes simultaneously. In our roadway layout, this change would be significant for a driver who is approaching the off-ramp, but has not yet changed into the lane that adjoins the ramp. Such a driver would be able to decide between overtaking a slow vehicle before changing into the lane adjoining the ramp or slowing to change lanes behind the slow vehicle. However, this behavior does not seem likely to significantly affect our simulations, for several reasons:

- We assume all vehicles are passenger cars. Slow vehicles occur only as the tail of a normal speed distribution, and therefore are somewhat rare.
- We focus on dense traffic. Overtaking for purely discretionary reasons will be a profitable driving tactic only infrequently.

2.4 Models

2.4.1 Traffic Generation
The multi-lane simulation requires traffic entering realistically at two points on the roadway: the beginning of the modeled section of the main roadway and the on-ramp from which entering vehicles merge into the main stream. The ramp entry is simple to model because we assume an initial velocity close to zero and a low density. The vehicle can simply be placed on the roadway and allowed to accelerate according to its free-driving control logic. Since density and speed are low, vehicles can be spaced so as to prevent the newly placed driver from reacting to the previously placed driver in an unexpected or unrealistic way.

The mainstream source is much more difficult. We must generate traffic that is equivalent to dense, high-speed traffic entering from an upstream, multi-lane highway segment. Under these conditions, the timing of vehicle entry is very sensitive—entering too soon will cause braking, but entering too late will not achieve the desired density and flow rate, or may cause unexpected accelerations. These disturbances could potentially propagate over time or space, causing unrealistic behavior for the entire simulation. By examining braking data and plots of velocities near the entrance, we were able to determine that this was not in fact a problem.

Entering vehicle desired speeds are normally distributed around a mean that varies by lane. This follows from the assumption that upstream drivers have, to some extent, stratified themselves

by desired speed. The mean is typically chosen in 2m/s increments, decreasing from the median lane out towards the curb lane. Vehicles generated in the merge lane are given desired speeds around the general population mean.

2.4.2   Highway

The simulated highway section is typically 4 lanes of length 1000 meters. The geometry of each lane center is a straight line. Lane width is 4m. The simulation is general enough to support any number of lanes of any length, and these parameters may be selected in the input.

The merge lane is separated from the main lane for 100 meters, after which vehicles are permitted to change into the main stream. They are not forced to exit the merge lane until the end of the simulated section of roadway, 900 meters downstream of the point where merging is first permitted. Vehicles that cannot merge at this point are simply recorded as merge failures, which are reported as a diagnostic of capacity. Do to the random nature of the traffic stream and variations between lanes, even a sub-capacity simulation run can exhibit a small number of merge failures. Realistically, most of these failures would not happen in practice due to main stream drivers making space for the merge, but we have no way to model this behavior.

2.4.3   Longitudinal Control and Dynamics

We used essentially the same vehicle longitudinal dynamics models as in the single-lane simulation. There were two minor changes.

1. In light of the increased scale of the simulation, we reduced the computational cost of the vehicle model by omitting the first-order lag in acceleration that was used previously.

2. The lateral controller (designed to model manual control) was allowed to set an upper bound on the longitudinal controller's commanded acceleration. This was done to allow the lateral controller to attempt to adapt to the speed and pattern of gaps when the vehicle is forced to merge. The details of this adaptation are discussed in the section on lateral control.

2.4.4   Lateral Control

After detailed testing of the MITSIM merging and lane change model in (2-4), we decided not to use it in our simulation. The model does not (nor was it intended to) adequately represent sequences of related driving decisions, but rather only individual, isolated decisions. The effect in our simulation was obviously incorrect when looked at over periods of time of more than a few seconds. For example, vehicles would often change to the left and then almost immediately change to the right while the external stimulus remained constant. The two individual actions may be consistent with the model's probabilistic assertions given the stimulus, but this behavior is likely to cause atypical traffic effects. The model's assertions may be valid for isolated events, but apparently not for a sequence of events.

One alternative is to use a simplistic and perhaps less tested model, which behaves reasonably in small-scale interactions, and attempt to tune the model for realistic macroscopic behavior. To do this, we looked for a source of macroscopic traffic observations such as lane change frequency and braking frequency at various levels of congestion. There have been recent projects at PATH to use computer vision techniques to identify lane changes and other events in freeway video. Detailed data from these projects became available too late to be incorporated into this project.

Nevertheless, our model owes much of its logical structure to the model developed in (2-4). The decision algorithm is described below.

We assume that the driver checks for lane change options on a fixed clock. If the driver is in a MLC (Mandatory Lane Change) situation, the clock period is 100 ms. In DLC (Discretionary Lane Change) situations, the clock period is 500 ms. The time to actually execute the lane change is assumed to be 2.0 seconds.

Each time the driver checks the lane change options, the driver makes a sequence of observations and decisions:
1. Are driving conditions are satisfactory?
2. Which lanes are suitable (in terms of speed, existence of gaps) to change into?
3. Is the nearest gap in the selected lane acceptable in terms of its size and its position relative to the driver's position?
These decisions are discussed in detail below.

The driver first decides whether current *driving conditions are not satisfactory* (DCNS). The driver model has access to the following variables, among others:

TABLE 1 Driver Model Access Variables

range	range to lead vehicle (from front bumper to rear bumper)
range_rate	difference between lead vehicle velocity and follower vehicle velocity
x_dot	current velocity of driver
desired_x_dot	desired velocity of driver
position	distance from start of merge lane
front_right_exists	true iff there is a vehicle in the lane to the right
front_right_x_dot	velocity of the vehicle in the lane to the right

The logical expression for DCNS for vehicles in the main stream (omitting some terms related to pacifying the edge effect) is:

DCNS: *DCNS1* **or** *C1*

where

DCNS1:   (range < 60) **and** (range_rate < 0.1) **and** (x_dot < desired_x_dot)

and

C1:   front_right_exists **and** (front_right_x_dot > desired_x_dot)

C1 expresses the condition that the driver is driving too slowly for the current lane, judging from current traffic conditions. This may of course be highly dependent on local regulations and customs.

In the case of a vehicle attempting to merge from the merge lane (which is a MLC situation), the expression is:

DCNS_MERGE: *DCNS1* **or** (position > 100)

In other words, the driver is stimulated to change lanes as soon as it is possible to do so.

After deciding that driving conditions are not satisfactory, the driver compares available lanes. In the merge case, the lane to the left is always chosen. If one of the adjoining lanes is clear ahead of the vehicle, that lane is chosen (with a preference for left, if both lanes satisfy the condition). If there are vehicles in the adjoining lane that are ahead of the subject vehicle, their locations and speeds are used to evaluate the lanes. If the speed in the target lane is greater than the driver's speed (plus a small threshold value) *and* the vehicle in the target lane is not braking at more than 1.0m/s/s, then the lane is selected, again with a preference for left. The threshold value is intended to prevent oscillation due to minor variations in speed.

Having chosen a target lane, the driver still needs to accept or reject the gap that is available in that lane. For this purpose, we use the formulas and parameters of (2-4), but replacing the probabilistic term, which is not correlated across successive lane-change decisions, with a constant term.

We define the lead_gap and lag_gap to be the bumper-to-bumper distance to the lead and lag vehicle in the target lane, respectively, should the subject vehicle change lanes immediately. We also define delta_v_lead and delta_v_lag to be the corresponding speed differences. Then we compute

```
lead_critical_gap = exp(0.508 – 0.420 * min(0,delta_v_lead))

lag_critical_gap  = exp(2.02  + 0.153 * min(0,delta_v_lag) +
                               0.188 * max(0,delta_v_lag))
```

as in (2-4). The gap is accepted if the lead_gap is bigger than the lead_critical_gap *and* the lag_gap is bigger than the lag_critical_gap.

Once the gap is accepted, the driver begins to execute the merge maneuver. If the vehicle is of type CACC, the control mode may switch to or from the communicating state, depending on the control type of the former and new lead vehicles. The maneuver completes after 2.0 seconds.

2.4.5   Evidence of Problems with the Models

In relatively low-density traffic, this model caused drivers to tend to oscillate between lanes. The problem is that each lane change decision is made independently, and the probabilistic decision model includes enough random elements (per decision) that if two lanes are relatively close in desirability, the chances are good that a driver will switch between them after a short delay. This problem is not resolved by (2-4) because, as mentioned in Chapter 4 of that work, the state sequences that would explain lane-change behavior grow exponentially with the number of observations. It would require a huge amount of data to support a model of dependence on past lane-change decision-making. However, this may not be a major problem in dense traffic, which is the focus of our work.

Another problem is that drivers tend to change lanes too frequently, compared to real world observations. Tuning the model parameters to match observations is difficult because so many parameters affect lane change behavior.

When all or most vehicles are manually driven, we often see spontaneous generation of slow, stationary queues in free flowing traffic. These queues do not dissipate. The vehicles in the queue slow almost to stopping. This should not happen unless caused by a severe incident of some kind; the simulation does not generate any such incidents.

The queues are not adequately explained by the disturbances caused by merging or lane changing. In fact, they even happen in single lane cases and with the demand level of the merge lane set to zero. This is not consistent even with casual observations of near-capacity conditions. Simulation runs involving some ACC vehicles do not have this problem, but of course these observations cannot be empirically corroborated on current freeways. We observed similar behavior with manual drivers in the earlier single-lane simulation, even though that simulation was implemented in a different language (SHIFT, rather than RedShift, as explained in 2.6 below). This suggests that the problem is either due to the driver model itself or due to some problem in its implementation in SHIFT that was carried over into its RedShift implementation. Implementing the driver model in some other simulation language might help to clarify this problem.

2.5   Simulation Experiments and Diagnosis of Capacity

As noted, we have several measures available to diagnose whether the specified demand levels exceed the capacity of the highway. Primarily, we are interested in

- Merge failure rate.
- Queue overflow.

It is easy to compute other measures using this software. For certain experiments, we have computed some of the following:

- Density by lane
- Lane change rate
- Hard braking rate
- Flow at exit
- Average speed at exit

We have also made use of the ability of the software to output time-history plots of vehicle positions, velocities, range-rates, and so on.

2.6   Implementation Issues

Increasing the scale of our simulation (by adding more lanes) and at the same time increasing the complexity of the control models (lateral control) placed a burden on our implementation to perform efficiently. We also had some problems with performance degrading over long running times with the software written in the first year.

We rewrote the simulation in a different, but closely related hybrid system modeling language (RedShift, in place of SHIFT), which has a more efficient implementation and is being actively

used in more projects. There is no degradation of performance over time in long running simulations. In addition, we used faster, though more complex, algorithms to implement some of the internal data management, without changing the meaning of the simulation. The most important of these algorithms is discussed in this section.

2.6.1 Driver Model Inputs From Nearby Vehicles

In the single lane case a driver model needs to have true information about the vehicle ahead of it. (What the model does with this perfect information is decided by the model itself — a model of manual driving may impose limitations on the driver's ability to perceive the surrounding vehicles and react to them.) The "link" from the follower vehicles to the leader vehicle changes only when a merging vehicle happens to merge into the gap between the two linked vehicles, replacing that link with two new links.

In the multi-lane case, each driver must receive information about many such links to nearby vehicles, not only in the driver's lane, but also in the immediately adjoining lanes to the left and right. Precisely, a driver needs to have a link to the nearest vehicles ahead of and behind it in its own lane and in each of the two (or fewer) adjoining lanes. The link is used to determine relative positions, relative velocities, and so on.

These six direct links are also the basis for broader queries about the state of traffic on the nearby roadway. A crucial difference in the multi-lane case is that the links change more fluidly over time than in the single lane case, as a result of speed differences as well as entrances, exits, lane changes, and merges. This phenomenon poses modeling questions, such as "How does a driver respond to a lane change by a vehicle entering the next lane to the left?" However, these questions are beyond our scope. We simply express our model equations and logic in terms of, primarily, the six directly linked vehicles, and, secondarily, the vehicles that can be reached from them in one or two steps.

The computational difficulty comes in trying to compute all this information as efficiently as possible, performing no more calculations than necessary. Recalculating all the links for all vehicles at every time step is expensive and scales poorly, since it involves searching a potentially large set of vehicles for, e.g., the nearest vehicle ahead and to the left. We capitalize on the fact that we know in advance what kinds of events invalidate the existing link structure and can carefully modify the link structure when these events happen. For example, the following images (Figure 2) show a vehicle in the third lane overtaking a vehicle in the lane to the right. The arrows display the link structure (forward links only, for simplicity). The overtaking vehicle's change to yellow is not important to this example (it signifies the controller's state changing from free driving to following another vehicle at a speed that is less than desired). The color of the arrows signifies only the direction, left (red), forward (black), or right (yellow), towards the linked vehicle.
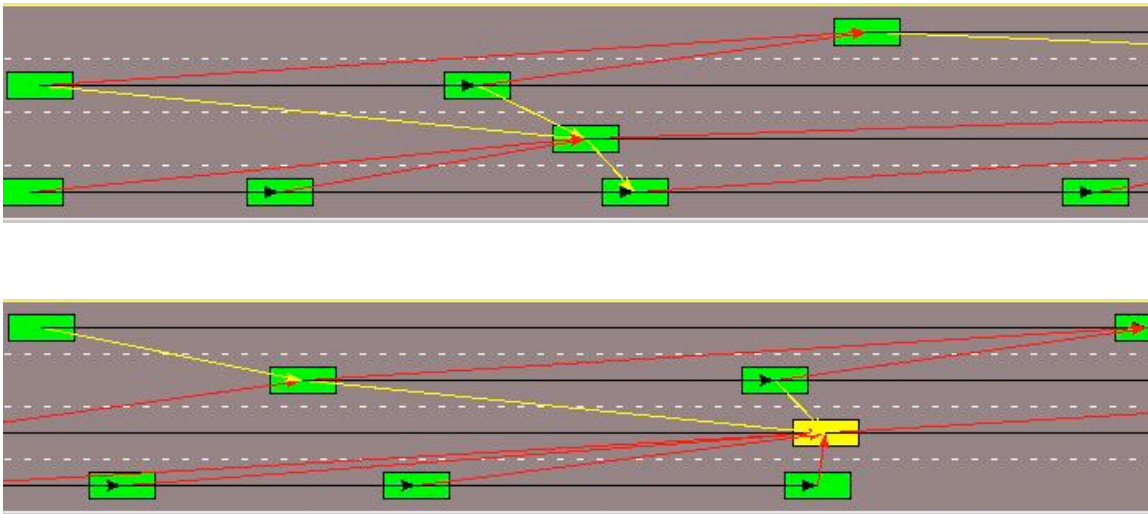
FIGURE 2 Vehicle Link Structure

This example is actually fairly simple: only two links change as a result of the overtaking. However, if the vehicle to the left and behind the yellow vehicle were to change lanes behind the yellow vehicle, all but one of the vehicles shown would have to adjust their links. Fortunately, these wider recalculations tend to be less frequent, especially in dense traffic.

Running simulations in debug mode ensures (with a small computational cost) that the links are maintained correctly, even though they are not explicitly recomputed at every time step. (This is done by performing local consistency checks to make sure that the link to the "nearest vehicle ahead of the subject vehicle in the lane to the left", for example, really satisfies this property).

This approach to computing relations between vehicles without performing search operations has an important consequence for expressing driver models: we can express driver decision directly as logical or numerical formulas in terms of the nearby vehicles and their relative distances and speeds, etc. The resulting simulation specification is simpler and runs more efficiently. We expect to reuse this optimization in future simulation work at PATH.

2.6.2   Features of the Visualization

The visualization (Figure 3) has several useful features:

- Zoom – display can be zoomed out to show 1000 meters of roadway and can be zoomed in at several levels of magnification (as in the other images in this report).
- Horizontal scroll – when zoomed, the display scrolls to show a window on the roadway.
- Interactive evaluation – the two boxes shown below the scroll bar can be used to enter commands and expressions and see the result. This can be used to search for vehicles satisfying some property. For example, "all vehicles between 100m and 200m that are moving faster than 20m/s".
- Periodic dump of simulation state – the state of the simulation is saved to disk every 10 seconds, and can be reloaded from this point.
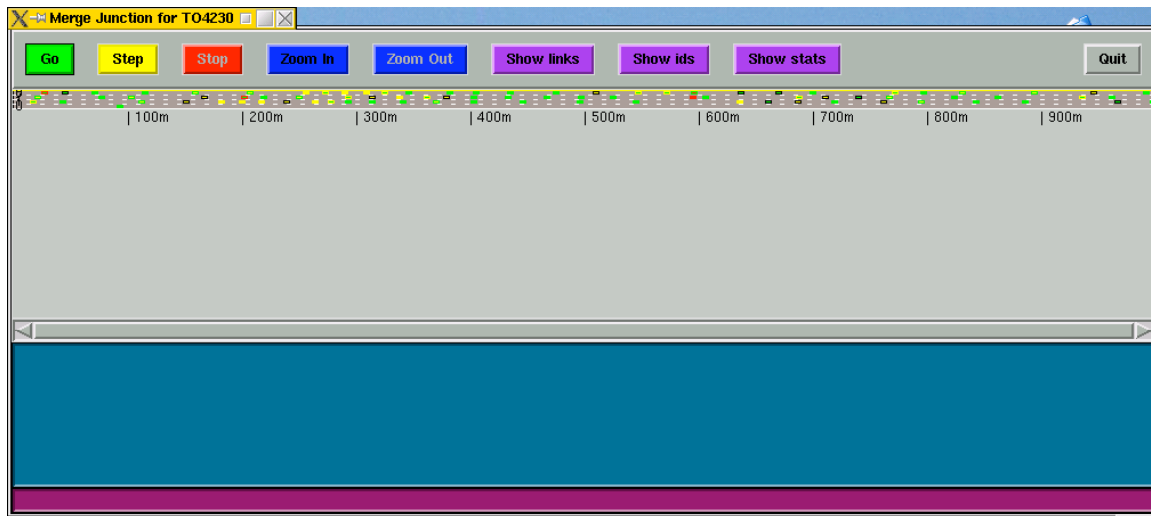
FIGURE 3 Visualization Features

2.6.3 Visualization of Driver State

The manual driver model is especially complex, and so it is useful to see some of its internal state in the visualization. Figure 4 shows an example.
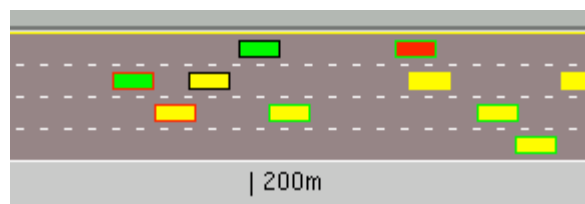
FIGURE 4 Driver State Visualization

The outline color and the body color for a vehicle are determined independently. The body color has already been noted:

- Red means hard braking (>2m/s/s).
- Yellow means driving conditions are not satisfactory (and the driver is looking for a lane-change opportunity).
- Green means the driver is either at desired speed or free to accelerate.

The outline color, in the case of the manual driver, indicates the driver's assessment of the current time gap:

- Red – the gap is considered dangerous.
- Yellow – the gap is critical – it could become dangerous very quickly.
- Green – the gap is large enough that accelerating to close the gap is desirable.
- Black – the gap is comfortable and no immediate action is needed.

These states are defined precisely in the driver model paper (2-6) and also reviewed in (2-1).

2.6.4 Visualization of Queue State

Since the queue size is used to diagnose when capacity has exceeded demand, it is useful to visualize the queue size. At the upstream end of the road, we show the number of vehicles that

have been generated by the arrival process, but have not been inserted in the traffic stream. In this example (Figure 5), the leftmost lane has one waiting vehicle. The next lane to the right has none. The remaining lanes each have two. Note that the far right lane is actually the merge lane.
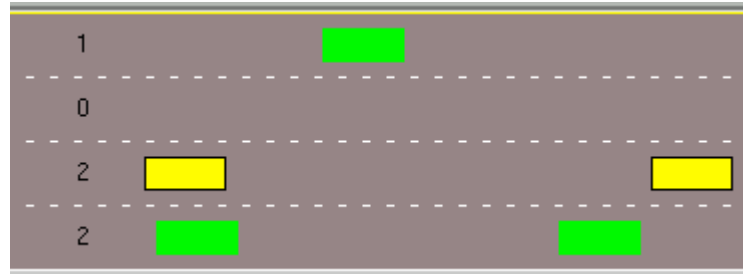
FIGURE 5 Queue State Visualization

2.7   Related Work Using the Software

2.7.1   PATH Task Order 4210
In the work leading to References 2-7, 2-8, and 2-9, the original single-lane software was adapted to study safety and capacity effects of vehicle-roadside and vehicle-vehicle communication at a merge point. In particular, the simulations showed a dramatic reduction in the braking effort resulting from a cut-in maneuver.

2.7.2   Work with Daimler-Chrysler RTNA
For this project, we needed fairly realistic traffic traces on a 3 to 5 lane freeway at varying levels of density and speed. The traces were used as input to a wireless networking simulation using the NS2 toolkit. Because of the problems with the manual driving model, we decided to use only autonomous ACC controllers and to set their time gap to 1.4 seconds to approximate incident-free manual driving.

Generating data for NS2 imposed some implementation difficulties. The simulation needed to have a fixed set of vehicles, with none entering or exiting. To accomplish this, we adapted our vehicle generation algorithm to recycle exiting vehicles as entering vehicles. In effect, this gave the highway a cylindrical topology. No additional vehicles entered from the ramp after the desired level of density was reached.

Papers describing this research have been submitted for publication.

2.7.3   Work with Toyota on DSRC
In work that is starting in April 2004, we are adapting the multi-lane simulation to represent a grid-like urban network to generate traces for NS2 simulations.

2.7.4   Cooperative ACC Human Factors Experiments
In this project, which is expected to begin in 2004, we will conduct experiments to determine the time gaps, which are acceptable to drivers of vehicles equipped with autonomous and cooperative ACC control.

We will use the data collected in the experiments to improve the realism of our models. The data collected will include the following:

- A distribution of time-gap settings for the sample drivers.
- Sets of conditions under which drivers disengage the ACC
- Sets of conditions under which drivers re-engage the ACC
- Driving behavior parameters for the moments following disengaging of the ACC.

The time-gap distributions will be used to calibrate our existing models. The other data will be used to develop switching logic for our control models so that they can incorporate both manual and automated control. With the new models, we can run simulations to generate results that can be compared to those in our earlier work.

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3.0 DEVELOPMENT OF VEHICLE-HIGHWAY AUTOMATION SYSTEM CONCEPTS FOR BUSES AND TRUCKS

3.1 Automated Bus Rapid Transit Systems
Automated Bus Rapid Transit (ABRT) may be viewed as the integration of several elements (3-1):

- Precursor systems such as transit information and operational improvements to enhance fleet management and provide more accurate and timely information to passengers, and collision warning systems to improve bus safety
- Bus Rapid Transit (BRT) service innovations in fare collection procedures, station design and location, and more attractive vehicle designs
- Automatic precision docking to enable buses to stop immediately adjacent to a loading platform, providing passengers with quick and easy boarding and alighting, even for those whose mobility is impaired
- Automated bus operation on segregated busways, providing rail-like ride quality while minimizing the needed right-of-way width.

3.1.1 Demonstrations and Testing: System Development
The *earliest* deployments of automation technologies in road vehicles will likely be on heavy vehicles—*buses* and *trucks*—operating on their own special rights-of-way because:

- It's easier to develop and acquire rights-of-way for public purposes like transit service
- In some cases, buses already operate on separate facilities, which could, if demand warranted, be switched over to automation
- Costs of the technologies are a smaller percentage of total bus costs and buses are used much more intensively so these costs are amortized faster
- Benefits in travel-time reduction, trip reliability and safety can be translated more directly into cost savings and revenue increases than for private passenger cars
- Customized, small-lot production of vehicles makes it possible to introduce automation technologies into the bus production process faster than for automotive mass production
- Packaging of new technological elements is easier on buses than on passenger cars
- Buses already have more onboard electronic infrastructure (such as data buses and electronic engine controls) to use as a foundation for more advanced capabilities than passenger cars
- Maturing technologies can be used more safely by professionally trained bus drivers on professionally maintained buses than by the general public on passenger cars that may not be well maintained.

3.1.2 Functional Components and Technologies
Bus transit automation will consist of automation functions and complementary elements (advanced public transportation systems) and include certain design attributes.

Automation functions:
- Precision docking
- Lane keeping

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- Automated speed and spacing control
- Maintenance yard operations

Complementary elements:
- Collision warning (forward, side, and rear)
- Vehicle diagnostics warnings
- Transit management center operations
  - Trip information for travelers at stops, stations and on-board buses
  - Electronic fare payment and pre-pay systems
  - Passenger counting systems
  - Traffic signal priority systems

Supporting design attributes:
- Bus design changes (low floor, wide doors)
- Bus stop/station design
- Infrastructure (bus bulbs, queue-jumpers, dedicated lane, check-in/check-out system, vehicle-roadside communications)
- Bus components (electronic throttle, brake, and steering control)

3.1.3 Benefits
The benefits of bus automation cover the following four primary groups:

- Transit properties
- Bus drivers (employees)
- Bus passengers (general public)
- Infrastructure owners and operators

The overall benefit will be an improved level of people movement, mobility, and quality of service. More specifically, the benefits for:

Transit Properties
- Reduced dwell time at bus stops for loading and unloading of passengers and avoiding need for maintenance-intensive wheelchair ramps by use of precision docking with low floor buses
- Precision docking at bus stops should help reduce tire scuffing against the curb, resulting in reduced wear-and-tear on the bus's tires and corresponding maintenance costs
- Rail-like line-haul service at a much lower capital cost
- Narrower rights-of-way and structures for busways are possible with the use of automated steering/lane keeping
- Potentially reduced operating costs (labor, fuel and vehicle productivity) for the automated portion of the bus trip (line-haul)
- Facilitating maintenance operations and saving yard space and labor, (i.e., reducing costs), ordinarily used to move buses through routine maintenance processes
- Greater vehicle and passenger lane-capacity, by enabling buses to operate at shorter headway than under manual control
- Reduced fuel consumption and emissions for buses that can operate in automated platoons with small enough separations that aerodynamic drag can be reduced

- Potential safety improvements should have direct benefits in terms of reduced insurance costs and less time lost from buses taken out of revenue service while being repaired for crash damage
- Increased ridership is a collateral benefit that could result from the cumulative effect of the previously stated benefits

Bus Drivers
- Automating precision docking at bus stops will make this operation easier and less stressful
- Automated line-haul operations reduce workload and stress

Bus Passengers
- Reduced travel time can result from having automated bus travel on a dedicated lane
- Improved bus stop arrival reliability
- Enhanced access to and from buses for mobility impaired passengers and reduced time for -loading and unloading of all passengers from bus stop - precision docking
- Smoother travel for passengers and increased passenger riding comfort
- Flexibility to perform in "dual mode": collection and distribution, and line-haul portion (even with intermediate stops). This may reduce need for passengers to make transfers, allowing passengers to remain on same vehicle for entire "door-to-door" service. The bus would "transfer" between a local neighborhood collector/distributor and a line-haul rail-like mode of operation.

Infrastructure Owners and Operators
- Permitting operations on narrower rights-of-way (reduced lane widths), thereby saving on land use and physical infrastructure costs
- Accommodating bus-only lanes in locations where they would otherwise not be able to fit at all

3.1.4 Incremental Cost Factors

There will be *incremental* costs associated with the use of bus automation technologies: additional electronic equipment installed and maintained on buses and busways and some additional protection of the busways to prevent intrusion by pedestrians, animals, unauthorized vehicles and debris.

Additional bus equipment is likely to consist of:
- Electronically controlled brake actuator (but this may soon become standard equipment associated with anti-lock braking anyway)
- Electronically controlled steering actuator
- Lateral-position sensing system
- Forward ranging sensor system similar to commercially available sensors for adaptive cruise control systems
- Vehicle-to-roadside and vehicle-to-vehicle data communications systems, which could build on existing and impending traffic signal priority system and DSRC technologies
- Collision warning sensor systems, which are already available for some vehicle applications and are under commercial development for others
- Onboard control computer similar in power to standard personal computers

At early stages of development, the total costs of these systems are likely to add no more than 5% to 10% to the cost of a new transit bus, and over time those Incremental costs should decrease by another factor of 4 or 5. It is important to consider these additional cost elements in the context of the costs of providing higher quality transit services by other means, such as light or heavy rail transit systems. In the context of such costs, these incremental costs are negligible.

3.1.5 Deployment Paths: Getting from Today's Bus Transit System to Automation
The specific development and deployment sequence will likely vary by location, depending on local and regional needs and constraints, so some locations will undoubtedly be able to make faster progress than -others. However, a generic sequence can be defined, -building on technologies already available or nearly available and then combining additional technologies and service elements in building-block fashion to achieve increasing levels of capability.

There are existing and currently emerging technologies commercially available today in at least one major sector of the world (Europe, North America, or Asia/ Pacific) for at least some vehicle classes or for specialized applications. They are:

- Forward collision warning
- Lane-departure warning
- Adaptive cruise control (ACC)
- Vehicle-roadside communication

Transit forward collision warning is being developed now by PATH for the San Mateo County (California) Transit District (SamTrans) under the sponsorship of the Transit Intelligent Vehicle Initiative.

Special capabilities can be added to transit buses with moderate levels of development and deployment costs:

- Vehicle-vehicle data communication for cooperative adaptive cruise control (CACC)
- Low-speed precision docking of buses at stops
- Automation of bus movements through maintenance facilities

A next level of deployment includes protected-lane opportunities particularly useful in locations where there are strong needs for enhanced transit services and/or where the right-of-way can be made available. In these locations, the operating agency can set aside a separated, protected lane for transit use. It then becomes possible to implement automatic steering control safely, permitting use of a narrower lane and relieving the bus driver of the steering responsibility.

Integrating a combination of these elements can form the basis of an initial operational scenario for bus transit automation, such as a pure line-haul run with few intermediate stops. Passengers could be collected from their origin locations at normal local bus stops, where the bus would be driven manually (except for the assistance of precision docking at stops). At the entrance to the protected busway or bus lane, the driver would switch the bus to automated operation and it would continue to operate automatically until it reached the busway's destination end. There could be intermediate stops along the automated busway, where the bus would operate exactly the way automated metros or automated guideway transit systems do now. At the end of the

automated busway, the driver would resume manual control of the bus and could take the passengers to their desired local bus stops. Through this kind of "dual mode" operation, the automated bus provides the collection and distribution flexibility of conventional buses and the line-haul efficiency and service speed of conventional rail transit, while saving passengers the inconvenience and time associated with transfers. This is the great service advantage automated buses can provide.

Over the longer term, with further advancements:

- Access to the ABRT lane could be provided to suitably equipped vanpools and then carpools
- Buses or vans could be coupled together more closely with their counterparts to form platoons, increasing capacity while reducing drag, to save fuel and reduced emissions
- Entry maneuvers could be automated with the addition of more sophisticated vehicle-roadside communication
- Higher-level management functions could be implemented to serve a network of connected ABRT lanes. These could indeed become the precursors to an automated highway network.

3.1.6 Challenges to Successful Deployment
Solution strategies are currently being sought for these and other challenges.
The transit industry may have concerns over the complexity and reliability of new technologies associated with bus transit automation. These concerns may influence the acceptability of technological changes that could potentially impact:

- Role of the driver (driver training, salaries, and work rules, additional driver responsibilities)
- Maintenance cost and complexity
- Safety
- Liability (changing risk and responsibility assignment).

Large-scale public transportation projects have the potential for influencing travel patterns and surrounding land uses. Automated bus transit operations, intended to replicate high-level transit service, (e.g., rail transit), though more flexible, may raise concerns over:

- How they fit into a region's overall transportation plans to be considered as a credible alternative for regional public transportation investment
- How their inherent flexibility over rail transit may be perceived instead as a lack of permanence and inhibit potential developers from investing heavily along such transit corridors.

3.2 Truck Automation Systems
Truck automation provides the capability for a truck to be driven automatically, without the intervention of a driver. This is most likely to be used for access to freight movement hubs such as ports and intermodal rail terminals or for long-distance driving in special-purpose truck lanes, where the trucks could be separated from other traffic to simplify their driving environment and reduce hazards. The trucks could be electronically coupled to form virtual trains or platoons in order to save fuel and reduce emissions, as well as to increase lane capacity. The driver could still serve a supervisory or managerial role, while the automatic

control system takes care of the tedious and stressful lower-level driving tasks. Or a driver could operate the first truck in the platoon while the others might be driverless.

Precursor technologies include drive- and steer-by-wire technologies, and also the various driver-assist and collision warning technologies currently under research with the IVI program and development by industry. But truck automation goes well beyond IVI and industry product development – in addition to the IVI safety goals, truck automation will directly and favorably impact fuel economy and other operating costs incurred in delivering goods to the consumer. Also, truck automation should contribute to reducing congestion by helping to increase highway capacity (3-2).

3.2.1 Dedicated Truck Lanes
Heavy trucks and passenger cars are so different from each other that it is in some ways remarkable that they generally share the same highway lanes almost everywhere today. Although this sharing of lanes simplifies the development and operation of the roadway infrastructure, it also has some significant adverse safety and economic implications. The relevant differences between trucks and cars include:

- Factor of up to 40 in mass
- Factor of up to 4 in length
- Factor of 4 to 20 in acceleration capability
- Factor of 2 to 3 in braking capability
- Factor of up to 2 in width

If trucks and cars were separated from each other on sections of highway that have heavy volumes of truck traffic it would be possible to separately optimize the design and operations of these costly infrastructure systems. This could offer a variety of significant benefits:

- Eliminating the truck-car conflicts and incompatibilities that are responsible for the majority of crashes involving trucks;
- Enabling trucks to avoid the traffic congestion caused by large volumes of automobile traffic;
- Enabling lane widths to be optimized for the different vehicle widths, so that the trucks could retain full-width lanes, but the cars could use narrower lanes, making it possible to fit more lanes within the same highway structures and rights of way;
- Enabling pavement design and maintenance to be optimized for the different loadings imposed by trucks and cars, so that costs could be significantly reduced for the lanes used only by the light-duty vehicles;
- Reducing the driving stress of drivers of both heavy and light vehicles, who would not need to worry about their incompatibility with the other class of vehicles;
- Facilitating use of different operating speeds where appropriate, such as on steep grades;
- Facilitating different schemes for paying for highway use, based on different priorities for timely arrival (particularly for trucks engaged in "just-in-time" deliveries).

3.2.2 Demonstrations and Testing: System Development
The earliest deployments of automation technologies will likely be on heavy vehicles _**buses** and **trucks** _ operating on their own special rights of way because:

- Costs of the technologies are a smaller percentage of total truck costs, and trucks are used much more intensively so these costs are amortized much faster

- Benefits in travel-time reduction, trip reliability and safety can be translated more directly into cost savings than for private passenger cars
- Special truck-only lanes are already under consideration for other reasons
- Customized, small-lot production of vehicles makes it possible to introduce automation technologies into the truck production process faster than for automotive mass production
- Packaging of new technological elements is easier on trucks than on passenger cars
- Trucks already have more onboard electronic infrastructure to use as a foundation for more advanced capabilities than passenger cars
- Maturing technologies can be used more safely by professionally trained truck drivers on professionally maintained fleets than by the general public on passenger cars that may not be well maintained.

3.2.3 Functional Components and Technologies

Truck automation will consist of both automation functions and complementary functions and will also include certain design attributes.

Automation functions include:
- Automatic speed and spacing control
- Lane keeping
- Automatic backing to a loading dock

Complementary functions may include:
- Forward, side and rear collision warning and/or avoidance
- Driver drowsiness detection
- Vehicle condition warning
- Truck management center (operations) for the processing of information from advanced communication and advanced vehicle location systems

Supporting design attributes include:
- Infrastructure (dedicated truck lane, check-in and -out, interface to local non-automated traffic)
- Vehicle (electronic fueling and brake actuator, steering control, driver-vehicle interface)
- Wireless communication (vehicle-vehicle and vehicle-roadway)
- Fault management system

3.2.4 Benefits

The benefits of truck automation are somewhat different from those for transit bus automation, based largely on the differences between the operating characteristics and normal uses of buses and trucks. The opportunities that can be gained from automating the driving of trucks were described in (3-2), and those were summarized in background material prepared for the planned (but subsequently cancelled) demonstration of the automated trucks:

- Commercial vehicle operators
- Truck drivers
- Infrastructure owners and operators
- General public/societal

The overall benefit will be an improved level of people movement, mobility, and quality of service. More specifically:

Commercial Vehicle Operators
- Economic benefits for commercial vehicle operators could be substantial. A heavy truck typically costs at least five times as much as a passenger car and would be driven annually at least ten times as far. Thus, the economic return from an investment in automation equipment is more attractive for trucks than for passenger cars. Moreover, it will probably be easier to install automation equipment on a truck than on a car for several reasons, e.g., less constrained space for packaging equipment, vehicles built to order in smaller quantities than passenger cars, shorter lead time from design to production.
- Perhaps most importantly, with truck platooning, the reduction in fuel consumption could be substantial – anywhere from 10 – 20 %. Hence, overall operating costs could be considerably reduced.
- Reduced and predictable travel times with automated trucks on dedicated lanes will improve the utilization of capital equipment, and improve the ability to meet performance targets for "just in time" deliveries.
- Potential safety improvements should have direct economic benefits in terms of reduced insurance costs and less time lost from productive use of trucks while being repaired for crash damage.
- Automated trucks could make possible significant changes in driving duty cycles and pay rates. Fully automated trucks could make it possible for drivers to travel long distances while resting, yet still earn payment. Some of the current problems with driver fatigue and duty hours conflicting with sleep cycles could be solved.

Truck Drivers
Personal safety, and ease and comfort of driving.

Infrastructure Owners and Operators
Roadway owners and operators are concerned with traffic flow and congestion and public safety, as well as roadway maintenance and other operating expenses. Benefits include:
- Lane widths could be optimized for the different vehicle classes
- Collisions involving trucks and light-duty vehicles could be greatly reduced, saving lives and reducing injuries
- Separate lanes could be used for different speeds, more suitable for separate vehicle classes
- Roadway structure and pavement designs could be optimized for different vehicle classes
- Permitting operations on narrower rights-of-way (reduced lane widths and/or fewer number of lanes required), thereby saving on land use and physical infrastructure costs

General Public/Societal
By reducing aerodynamic drag when trucks are traveling in platoon formation, automation can reduce emissions and contribute to overall improvement in air quality, as well as saving energy and reducing dependence on imported petroleum.

3.2.5 Incremental Cost Factors

There will be incremental costs associated with the use of truck automation technologies, primarily in terms of additional electronic equipment installed on trucks and dedicated truck lanes (together with their continuing maintenance), and some additional protection for the dedicated lanes to prevent intrusion by unauthorized vehicles and debris.

Additional truck equipment is likely to consist of:

- Electronically-controlled brake actuator that may soon become standard equipment associated with anti-lock braking anyway
- Electronically-controlled steering actuator
- Lateral-position sensing system
- Forward ranging sensor system similar to commercially available sensors for adaptive cruise control systems
- Collision warning sensor systems which are already available for some vehicle applications and are under commercial development for others
- Vehicle-to-vehicle data communications system
- Vehicle-to-roadside data communications system which could build on existing and impending electronic toll collection technologies
- Onboard control computer that needs to be no more powerful than standard personal computers

3.2.6 Deployment Paths: Getting from Today's Trucks to Automation

Existing precursor technologies are:

- By wire control
- Forward collision warning
- Lane-departure warning
- Adaptive cruise control
- Vehicle-roadside communication
- Electronic tow bar

Some of these are being developed by manufacturers and suppliers, and some are undergoing testing via the USDOT IVI Program and the California PATH Program. The electronic tow bar concept has been tested by DaimlerChrysler, under a European Commission program called CHAUFFEUR.

With the above as a basis, special capabilities can be added to trucks with moderate levels of development and deployment costs, including:

- Vehicle-vehicle data communication for cooperative adaptive cruise control
- Automated backing function or assistance

A next level of deployment includes dedicated-lane opportunities. This would be particularly useful in locations where there is high truck volume, and where congestion concerns are quite important. It could also be useful where road maintenance and safety with car-truck interactions are important. There are locales (e.g., I-15, I-710 and SR-60 in Southern California, and I-10 across the U.S.) where such dedicated lanes have been considered. It then becomes possible to implement

automatic steering control safely, permitting use of a narrower lane and relieving the driver of the steering responsibility.

These technologies can form the basis of an initial operational scenario for truck automation, such as a long-distance line-haul operation.

At the entrance to the dedicated lane, the driver would switch the truck to automated operation, join behind another trucks and operate automatically until he reached his destination.

Over the longer term, with further advancements, the entry maneuvers could be automated with the addition of more sophisticated vehicle-roadside communication and higher-level management functions could be implemented to serve a network of connected dedicated truck lanes. These could indeed become the precursors to an automated highway network.

3.2.7 Challenges to Successful Deployment
The challenges discussed here are currently under investigation to find solution strategies (3-3):

- Industry concerns about the complexity, reliability and maintainability of new technologies
- Changing role of the driver (hours of service, driver training, salaries, and work rules, additional driver responsibilities)
- Safety
- Insurance
- Liability (changing assignment of risk and responsibility).
- Labor-management relations
- Regional planning and land use issues
- Inter-organizational relationships: competition (with intermodal rail) and partnerships

In the end, the benefits (primarily in reduced operating costs via fuel economy but with the addition of others discussed above) for each stakeholder category must be clear, calculable and attainable. If so, the decision from commercial as well as public sectors will be justifiable and easier.

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3-1   Shladover, S.E. "Bus Rapid Transit and Automation – Opportunities for Synergy", *Proceedings of Seventh World Congress on Intelligent Transport Systems,* Turin, Italy, November 2000.

3-2   Shladover, S.E., "Opportunities in Truck Automation", *Proceedings of Eighth World Congress on Intelligent Transport Systems*, Sydney, Australia, Paper No. ITS00155, October 2001.

3-3   Miller, M.A., "Truck Automation: What are the Institutional Challenges", *Proceedings of the Ninth World Congress on Intelligent Transport Systems*, Chicago, United States, October 2002.

**4.0   INVESTIGATION OF THE INTERNATIONAL STATE OF RESEARCH AND
         PRACTICE FOR VEHICLE HIGHWAY AUTOMATION SYSTEMS**

In 2000-2001 timeframe, PATH became aware of a potential collaborative opportunity with the European Commission (EC) in the area of advanced vehicles control and safety systems and automated highway systems. Capitalizing on this opportunity was possible and successful because of a strong linkage between the proposed European research and in-house PATH research in this area, which was ongoing at the time. As a result, PATH entered into an unfunded research collaboration agreement with the partners in the EC-supported project "Towards Sustainable Town Development: A Research on Deployment of Urban Sustainable Transport (STARDUST)". Resulting from this agreement, the PATH Program became a member of the STARDUST Consortium and performed mutually agreed upon tasks (as part of the collaboration) and sharing research on topics of mutual interest.

The overall objectives of the STARDUST project were to deliver an assessment of the potential for driver assistance systems to contribute to the sustainable urban development of European cities and to provide a credible, independent analysis of the environmental and traffic efficiency impacts of such systems as well as the impacts on aspects of urban development such as social life, economic viability, cultural life, safety, etc. The project will develop realistic deployment paths for advanced vehicle guidance, advanced vehicle control and safety, and automated highway systems with an aim to provide maximum benefit to all stakeholders.

As a member of the STARDUST Consortium, PATH's primary task was to perform a review of the state of the art of research, technology demonstrations, prototypes, and simulation results for advanced vehicle guidance systems, advanced vehicle control and safety systems, and automated highway systems. PATH focused its efforts on the United States and Japan, the Asia's leader in the field of advanced vehicle control and safety systems. The review from the European perspective was carried out by another member of the STARDUST Consortium.

The next two sections contain the reviews for the United States and for Japan and reflect the state of affairs as they were when this work was done in 2001. The full text of the review for Europe is provided in the Appendix to this report.

4.1   United States

4.1.1   Institutional Context: Overview of Government Roles
The USDOT is one of the weakest departments in the U.S. government because of its structure. It was assembled in 1966 by combining a variety of previously independent agencies under a single roof, but those agencies have retained much of their prior independence. This makes it very difficult for them to speak and act as "one DOT", even though that is the stated aim of the Secretary of Transportation. The rivalries among the agencies within the USDOT are remarkably similar to the rivalries among the competing Ministries in Japan, but in this case they are exacerbated because they are engaged in something of a "zero sum" game when trying to get their budgets approved.

The primary elements of USDOT are known as "modal administrations", and the ones that are relevant to ITS issues are:

- Federal Highway Administration (FHWA) – collects federal gasoline tax and then allocates the large majority of those funds to the states according to complicated formulas determined by Congress. They also conduct some national research on road transportation issues through their Turner-Fairbank Highway Research Center (TFHRC). Their interests are in roadway infrastructure and operations and maintenance.
- National Highway Traffic Safety Administration (NHTSA) – is responsible for regulating the safety of all new motor vehicles sold in the U.S., through their Federal Motor Vehicle Safety Standards (FMVSS). They also investigate safety problems and conduct research on ITS issues in their Office of Crash Avoidance Research (OCAR).
- Federal Transit Administration (FTA) – provides funding to public transit agencies to help them pay for capital costs of construction of new facilities and purchase of buses. They sponsor some limited research on advanced technologies for transit.
- Federal Motor Carrier Safety Administration (FMCSA) – is responsible for regulating the safety of interstate truck and motor coach (bus) transportation, including systems that can be retrofitted to existing vehicles, and has major responsibility for defining rules for truck operations (limitations on drivers' hours of service). They conduct limited research on truck safety issues, especially on driver drowsiness.

USDOT began its activities on ITS in 1992, following the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA), which specifically authorized work on what were then known as "Intelligent Vehicle-Highway Systems". Because of the rivalries among these agencies, USDOT created an ITS Joint Program Office (JPO) to try to coordinate activities across the agencies and independently allocate ITS funding to them. However, the JPO was located within the FHWA, which immediately created tensions with the other agencies, and it has not had sufficient authority to coordinate effectively, especially with NHTSA. The new Secretary of Transportation is considering moving the JPO out of FHWA and into his own office in order to try to get above the rivalries.

Between 1992 and 1997, USDOT had two major research programs addressing AVCSS issues. FHWA had the Automated Highway System (AHS) program, while NHTSA-OCAR had the program of crash avoidance research. In 1997, USDOT decided to stop its work on AHS because they were concerned it would take too long to develop and switched their attention to a new program called the Intelligent Vehicle Initiative (IVI), which incorporated the NHTSA-OCAR program and added other elements to address safety of transit buses, heavy trucks and "specialty vehicles" (snowplows, police vehicles, etc.). The annual budget for the IVI program is about $30 million, which is considerably less than the automotive and supplier industries are spending on AVCSS development on their own.

States
Under the Federal system in the U.S., the USDOT does not design, build, own, operate or maintain any highways. The primary highways (Interstates, U.S. and state highways) are the responsibility of the state departments of transportation. They receive significant funding by formula from the FHWA, but they generate even more funding from their own gasoline taxes, and they decide how to spend all of this money.

Political pressures in Washington D.C. have forced the USDOT to send an increasingly high percentage of the federal gasoline tax money directly to the states and to keep a smaller percentage for direct expenditure by USDOT. The result has been a trimming of the budgets available to R&D at the federal level. However, under the funding formulas established by law a

fixed percentage of the federal gasoline tax money sent to the states must be used for "state planning and research" (SP&R). These SP&R funds have been growing significantly in recent years, with the result that more and more of the transportation research decisions are being made at the state level. The SP&R planning funds represent 1.5% and the research funds 0.5% of the federal highway formula funds allocated to each state. In the case of California, these represent $48 million and $16 million respectively during the current year, showing how significant these funding levels can be relative to the funds that are spent directly by USDOT.

California Department of Transportation (Caltrans)
Caltrans recognized the need for ITS in 1986, when it was doing long-term studies of how to meet the growing demand for travel in the rapidly growing urban areas of the state. It created the PATH Program in cooperation with the University of California to explore technologies to address the severe anticipated traffic congestion problems, and from the start of this effort in 1986 one of its major concentrations of attention has been on development of automated highway systems (AHS) to significantly increase the capacity of dedicated highway lanes. The California program began more than five years before the national program, and in fact it was missionaries from California who traveled around the country to convince people in other states of the need for the national program that was eventually started.

PATH has already invested more than 550 labor years of effort on AHS research and development. Caltrans is interested in a wide range of AVCSS applications and is interested in providing cooperative roadway infrastructure to interact with suitably equipped vehicles if these can be shown to improve highway efficiency, capacity and/or safety.

Other State Activities
Other states that have shown significant interest in AVCSS activities have been Minnesota, Virginia and Arizona. The states have started to join forces to work together on "multi-state pooled fund projects", using their SP&R funding. Two such multi-state projects are particularly relevant here:

IVI Infrastructure Consortium
California, Minnesota and Virginia have joined together to work on development of systems that can enhance safety by enhanced vehicle-infrastructure interactions. Their initial focus is on development of cooperative "intersection decision support" systems to help reduce intersection crashes, and future work will probably be aimed at road departure crashes as well (See also Section 2.2.1.4).

Cooperative Vehicle-Highway Automation Systems (CVHAS) Pooled Fund Project
California has been joined by ten other states in this new project to explore how to use cooperative vehicle-highway automation technology to help reduce traffic congestion. The initial focus of work here will be on applications of automation to transit buses and heavy trucks, but it is expected to extend to passenger cars as well. The initial state members (California, Arizona, Washington, Utah, Missouri, Minnesota, Illinois, Florida, Georgia, New York, and Maryland), representing 35% of the population of the country, are recruiting additional participants from private industry and international participants as well. The first non-state member to join was Honda R&D of North America, sowing the seeds of public-private partnership, which is important for long-term success here (See also Section 2.2.1.3).

4.1.2 Advanced Vehicle Control and Safety Systems

Government/Public Sector Programs
Activities exist at both the federal and state levels. With limitations in the budgets available to be spent directly at the USDOT, an increasing percentage of this work is being done at the state level, using either state funds or state shares of the federal gasoline tax revenues (2% of the allocation to each state being designated for "state planning and research" – SP&R).

<u>Intelligent Vehicle Initiative (IVI) Program</u>
The IVI Program is USDOT's program to enhance driving safety by use of autonomous vehicle sensing and warning technologies. This builds on a legacy of prior research by the NHTSA Office of Crash Avoidance Research (OCAR). Research focuses on eight safety-related areas: rear-end collision avoidance, roadway departure collision avoidance, lane change and merge collision avoidance, intersection collision avoidance, driver condition warning/impairment monitoring, vision enhancement, vehicle stability, and safety impacting systems. There are two primary dimensions within which IVI Program work is being conducted: Vehicle platforms and Generations. The four vehicle platforms are light vehicles (passenger vehicles, light trucks, vans, and sports utility vehicles), commercial vehicles (heavy trucks and interstate buses), transit vehicles (non-rail vehicles operated by transit agencies), and specialty vehicles (emergency response, law enforcement, roadway maintenance vehicles). The other dimension describes both the level of technical capabilities and sophistication, and the timeframe along which systems are expected to be ready either to enter production preparation or planning. Alternative timeframes are more commonly referred to as Generations 0, 1, and 2. Generations 0, 1, and 2 systems are those that are expected to enter production preparation/planning by 2003, 2008, and 2012, respectively. Naturally, as the program progresses from Generation 0 through 2 and beyond, the level of technical capabilities will advance.

There are currently eight on-going projects as part of the IVI Program (Table 1) encompassing driver assistance safety and information systems, specialty vehicle use, commercial vehicle use. In particular, there are four Gen 0 Field Operational Tests (FOTs) that serve as a transition between research and development (R&D) and full-scale deployment of user services. These tests permit an evaluation of how well newly developed AVCSS technologies work under real operating conditions and assess the benefits and public support for the product or system. The field tests are to be conducted on vehicles in a "real world" operational roadway environment under actual transportation conditions. The Generation 0 IVI FOTs are designed to accomplish the following objectives:

1. Evaluate the performance of proposed advanced safety systems and provide a means of informing transportation decision-makers and the general public of potential opportunities for improved safety.
2. Accelerate deployment of advanced technologies that enhance safety by providing a substantial level of understanding of risks of all types including, but not limited to, marketing, operating, crash, and liability risks, thus reducing deployment risks.
3. Forge additional strategic partnerships with transportation stakeholders as an effective model of public-private cooperation for the development of advanced safety systems.
4. Apply and assess the state-of-the-art in benefits analysis for advanced vehicle-integrated crash avoidance systems.

Generation 0 field tests are operational tests of vehicles containing advanced safety systems that are expected to begin production preparations in light passenger vehicles, commercial vehicles, transit vehicles, or specialty vehicles before the end of FY 2003. The U.S. Department of Transportation does not expect to compare safety advances offered by different manufacturers, but rather to evaluate the gains of specific advanced systems in specific vehicle types/models offered by a manufacturer.

Table 1 On-Going U.S. IVI Program Projects

TITLE	DESCRIPTION	END DATE
Benefit Assessment of Intelligent Vehicle Systems	Develop tools and methodologies to assess safety and other benefits of intelligent vehicle services	September 2001
Automotive Collision Avoidance System/Field Operational Test (FOT)	Document and report results of analyses determined from testing rear-end collision warning systems in operational environments, including estimated safety benefits derived from such systems	December 2004
In-vehicle Display Icons and other Information Elements	Develop analytically- and empirically-based design guidelines for in-vehicle icons.	August 2001
Operational Review of Specialty Vehicle	Perform preliminary needs assessment for Specialty Platform	August 2001
Transit Rear Impact Collision Warning System	Develop functional requirements for rear impact collision warning system; install prototype system for field test evaluation; develop preliminary performance specifications for a rear impact collision warning system	2002
Transit Side Collision Warning System	Investigate, develop, and test performance specifications for a transit bus side collision warning system	April 2002
Transit Frontal Collision Warning System	Develop technical and requirement specifications for a forward-looking, transit-vehicle mounted crash warning system; install system on two transit buses for field test and evaluation	January 2002
Collision Avoidance Driver-Vehicle Interface	Develop preliminary driver-vehicle interface for a transit bus longitudinal and lateral collision avoidance system	February 2003
Gen 0 FOT – Minnesota DOT (Specialty vehicle)	Test rear-end and roadway departure collision warning systems involving snowplows.	December 2002
Gen 0 FOT – Freightliner Corp.	Test performance of Roll Stability Advisor (an in-cab device designed to inform truck driver what rollover threshold of combination (cab & tractor) is and how close to that threshold driver is driving.	December 2002
Gen 0 FOT – Mack Trucks, Inc.	Test performance of in-vehicle warning systems relative to hazardous materials incidents and crashes.	December 2002
Gen 0 FOT – Volvo Trucks North America, Inc.	Test performance of tractor equipped with advanced safety systems; Comparison will be made to control group of tractors equipped with standard drum brakes, anti-lock brake controls, and currently used Eaton-Vorad collision warning system.	June 2003

Sources:

1. Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation, *IVI Program Business Plan* (http://www.its.dot.gov/ivi/ivi.htm)
2. Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation, *ITS Projects Book* (http://www.itsdocs.fhwa.dot.gov/jpodocs/EDLBrow/@@_01!.pdf)
3. U.S. Department of Transportation Federal Transit Administration, *Benefits Assessment of Advanced Public Transportation System Technologies Update 2000*, FTA-MA-26-7007-00-4, DOT-VNTSC-FTA-00-02.

There are also 56 completed projects that were funded under predecessor programs to IVI, covering a myriad of topics. Of particular relevance in the AVCSS area are the following:

- Crash Avoidance Metrics Partnership (CAMP) – Rear-End Collision Warning Research, Test Metrics and Test Methodology Development Program
- Intelligent Cruise Control Field Operational Test
- Intersection Collision Avoidance Using ITS Countermeasures
- Performance Specifications: Countermeasures Against Lane Change, Merging, and Backing Collisions
- Performance Specifications: Countermeasures Against Rear-End Collisions
- Performance Specifications: Countermeasures Against Roadway Departure Collisions
- Feasibility of Sensor-Friendly Vehicles and Roadways to Support Intelligent Vehicle Services

General topic areas encompassing these and other projects include:

- Advanced vehicle control systems (vehicle-to-vehicle communications, sensor technologies, vehicle-follower longitudinal control)
- Safety systems (collision/crash warning and avoidance systems)
- Human factors

A complete description of the projects may be found in the *ITS Projects Book* (See above source).

Within the transit arena, the two currently on-going yet separate projects investigating side collision avoidance and forward collision avoidance systems, respectively, along with the driver-vehicle interface project (See Table 1) will be integrated into a single coordinated Gen 1 Field Operational Test of collision warning systems in the 2001 through 2004 time frame. More information may be obtained from the Web site source: http://www.its.dot.gov/ivi/transitFOT.htm.

Within the light vehicle platform, a road departure Field Operational Test (FOT) for a system that can warn a driver when he/she is about to drift off the road, or is traveling too fast for an upcoming curve is under development and will be implemented in the 2001-2003 timeframe.

California PATH Program
The California Partners for Advanced Transit and Highways (PATH) Program at the University of California has been active in developing vehicle-highway automation technologies

since 1988, under the sponsorship of the California Department of Transportation (Caltrans) and the U.S. DOT as well. California PATH first implemented separate lateral and longitudinal control systems on full-scale automobiles in 1991 and '92. From that point, PATH enhanced the performance of those control systems through a series of research, development and demonstration projects, climaxing with fully integrated automatic control of platoons of automobiles in "Demo '97" (See Section on U.S. Demonstrations for "Demo '97, Platooning Scenario).

The core of PATH's Advanced Vehicle Control and Safety Systems (AVCSS) Program is its collection of research projects funded by the Caltrans Division of New Technology and Research. Currently, this research program encompasses the following major topic areas (Additional information may be obtained from the following Web site source: http://www.path.berkeley.edu):

- Vehicle control
    - o Vehicle control experiments and field testing
    - o Vehicle control under abnormal conditions
    - o Control of heavy duty vehicles

- Vehicle safety
    - o Vehicle braking control
    - o Fault detection, diagnosis and management
    - o Vehicle safety assessment and safety enhancement

- Enabling technologies
    - o Communication systems
    - o Advanced vehicle location
    - o Human driver models
    - o Human-Machine interactions
    - o Aerodynamics
    - o Real system deployment
    - o Emissions model

- System operations
    - o AHS deployment
    - o Bus rapid transit

Other major AVCSS research PATH is working on include the following:

Forward Collision Warning:
In 1999, Caltrans, San Mateo County (California) Transit Authority (SamTrans), and PATH initiated work on a frontal collision warning system (FCWS) using advanced sensing and computer technologies. The project team is completing the accident analysis phase of the project and will complete the project in 2002 when it will be integrated with other transit-related Intelligent Vehicle Initiative projects (See Section on IVI Program).

Snowplow (Specialty Vehicle) Automation:
Since 1998, California PATH, teamed with the Advanced Highway Maintenance and Construction Technology (AHMCT) Center at the University of California at Davis and the

Western Transportation Institute of Montana State University, has undertaken a research, development and evaluation program centered on implementing and deploying driver assistance for snowplows. These snowplows provide a lateral guidance function and collision warning information to the snowplow operator – an essential function in the hazardous mountainous, low-visibility and whiteout conditions they often encounter. It is designed to provide critical safety information to drivers of snowplows and other specialty and general-purpose vehicles. The lateral guidance assist system consists of a lateral position reference system, using magnetic markers along the centerline of the test lane, connected to a Human Machine Interface (HMI). The Collision Warning System consists of a forward-looking radar system and uses the same HMI interface as the lateral guidance assistance system.

Automotive Collision Avoidance System:
In 2000, California PATH joined the General Motors Corporation/Delphi-Delco Electronics Systems team to work on developing a collision warning system integrated with an adaptive cruise control system in preparation for a Field Operational Test. The FOT will assess the impact of this integrated Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC) system. PATH provided a simulation to evaluate alternative threat (i.e., collision) assessment algorithms. The FCW function assesses conditions ahead of the vehicle and alerts the driver of rear-end crash hazards while the Adaptive Cruise Control (ACC) function activates the brake and throttle to maintain a specified headway when following a slower vehicle. It will provide warnings to the driver, rather than taking active control of the vehicle. The FCW and ACC functions will be implemented using a combination of (a) a long-range forward radar-based sensor that is capable of detecting and tracking traffic, (b) a forward vision-based sensor that detects and tracks lanes and (c) GPS and a map database to help ascertain road geometry. (Additional information may be obtained from the following Web site source: http://www.nhtsa.dot.gov/people/injury/research/pub/ACAS/ACAS-fieldtest/index.htm

Near-term Heavy Vehicle Control Research: 2001-2003:
Under Caltrans sponsorship, PATH has begun vehicle development work in preparation for Demo 2003—a large-scale demonstration of automated buses and trucks. (See Section on U.S. Demonstrations for Demo 2003).   .

CVHAS Pooled Fund Project
Cooperative Vehicle-Highway Automation Systems (CVHAS) are systems that provide driving control assistance or fully automated driving, based on information about the vehicle's driving environment that can be received by communication from other vehicles or from the infrastructure, as well as from their own on-board sensors. By combining machine intelligence in vehicles and the roadway infrastructure, and using wireless communication technology to exchange information, the vehicles and roadways can function as a truly integrated transportation system, exceeding the capabilities possible when vehicles and roadways fail to share information. The CVHAS pooled fund project is a federal program whose main purpose is to use the pooled resources from public and private sector partners to research, develop, evaluate and deploy CVHAS solutions to improve transportation mobility, safety, and environmental quality. As part of its mission, CVHAS seeks to facilitate the sharing of technological and institutional experiences gained from its projects and the projects of its individual members.

Current work includes an on-going effort at recruiting new members, including from other U.S. States, international participants, and private industry, providing input to the U.S. DOT via

ITS-America on the reauthorization of the primary piece of transportation legislation in the U.S. (Transportation Equity Act of the 21st Century: TEA-21) and the soon-to-begin transit and commercial freight movement deployment case studies. The eleven pooled fund project states are focusing their first year of activity and resources on three deployment case studies for bus (1) and truck applications (2) in two of the CVHAS-member states.

Case studies of applications of CVHAS in specific sites are needed to shed light on important issues such as the definition of system operating concepts, system designs, institutional opportunities and constraints and system benefits and costs to the various stakeholders, as well as to society as a whole. These case studies will focus on the solution of actual transportation problems that can then provide a basis for focusing technical decisions and refining system design trade-offs. The findings of the case studies can be used to show the more general benefits of CVHAS as part of the outreach messages for the PATH/Caltrans Demo 2003. Case studies for diverse locations around the U.S. (and particularly locations outside California) can provide direct evidence of the broad, national applicability of CVHAS, to help stimulate broader interest in CVHAS. Three deployment case studies are being planned for and will commence in summer of 2001.

One of the commercial vehicle case studies involves the use of a straddle carrier, a four-wheeled, self-propelled vehicle that transports freight containers that straddle a line of railroad cars to load or unload containers from a train. The case study will investigate the use of an automatic guidance system for the straddle carrier when running over the rail cars, which would permit the carrier to operate at greater speed and efficiency than when under manual control.

The second commercial vehicle case study takes place in Chicago, Illinois in the U.S. Midwest—the primary hub of the U.S. national rail system where much of the intermodal freight traffic involves transfers between rail companies and rail yards and much of this handled by local truck hauls with tremendous impact on the street system. The case study will evaluate the physical, technological, economic, and environmental impacts of use of electronically guided vehicles operating on an exclusive roadway to perform these intermodal container interchange movements.

The third case study involves bus rapid transit in the Chicago, Illinois central business district (CBD) for a region of nearly 8 million people. The case study will investigate the physical, technological, economic, and environmental impacts of use of electronically guided vehicles operating on an exclusive or semi-exclusive roadway or bus lane to provide the collection and distribution services needed in this region.

More detail may be obtained from the CVHAS Web site: http://www.cvhas.org/.

IVI Infrastructure Consortium
The Infrastructure Consortium (IC) was established in June 1999 in response to a request by the USDOT's ITS Joint Program Office to transform the focus of the hitherto named "Specialty Vehicle Consortium" from snow removal (and some emergency vehicle) to the more general class of vehicle-highway cooperative systems. The U.S. DOT requested two foci, which they requested be addressed serially: intersection collision warning and roadway departure warning.

The "Specialty Vehicle Consortium", consisting of three of the most forward-thinking and influential State DOTs – Caltrans (lead), Minnesota DOT, and Virginia DOT – responded positively to the U.S. DOT and considering both "pooled funds" (returned in the form of planning and research funding from the Federal gas tax) and anticipated Federal funds began planning for a joint project to address intersection collision warning.

The topic of roadway departure warning is thus far not addressed by the IC, although the U.S. DOT has begun studying the problem (See Source 1 below).

Source:

1. Kenneth Freeman, "Intersection Decision Support" panel presentation in *Cooperative Vehicle Highway Systems, 11th Annual Meeting of the Intelligent Transportation Society of America*, Miami, Florida, June 7, 2001.

Minnesota DOT Programs
The main center for Minnesota AVCSS research is the ITS Institute, which is an affiliate of the University of Minnesota's Center for Transportation Studies. The foci of AVCSS research at the ITS Institute includes several "enabling" areas (Source: #2 listed at the end of this section.):

- Human performance and behavior
- Computing, information, and communication
- Sensing, measurement, and control systems
- Tools for modeling
- Related social and economic policies

The ITS Institute specializes in research associated with transportation in northern climates, particularly with respect to safety in rural environments (Source #1 listed at the end of this section). A host of projects related to AVCSS are performed at the ITS Institute. They include projects that focus on human machine interface and enabling technologies such as GPS-map database, sensing and communications (Source: #2). Three projects are particularly noteworthy: the Minnesota Specialty Vehicle Initiative (IVI Snowplow), SAFETRUCK, and Bus Rapid Transit on Highway Shoulders (Source: #2).

Minnesota Specialty Vehicle Initiative (IVI Snowplow):
The US DOT IVI has funded the ITS Institute and its partnership of State government, local government, private companies a Gen 0 (i.e., "current generation") Field Operational Test (FOT) of specialty vehicles. While other emergency vehicle services are contained within this FOT, the focus is the snowplow. Key technology areas are:

- Integration of high-precision GPS and inertial measurements
- Identification and location of relevant fixed elements local to the road in a "geospatial database"
- Radar-based sensing of mobile obstacles
- Driver-vehicle interface to include content of presentation, a head-up display design, haptic steering wheel feedback, and a vibrating seat
- A vehicle data acquisition system: for analysis of system performance, road weather conditions and driver behavior

The IVI snowplow is currently undergoing field tests and is expected to collect operational data beginning in late 2001.

SAFETRUCK:
The SAFETRUCK project was conceived to examine potential safety-enhancing sensing and control technologies. It consists of an International 9400 series Class 8 tractor equipped with electronically controlled engine, transmission, in addition to anti-lock brakes and traction control. The research examines multiple AVCSS approaches intended to prevent road departure accidents to include a "virtual bumper" controller designed to emulate a protective envelope around the vehicle, and the use of DGPS and wireless data transmission between vehicles.

Bus Rapid Transit on Highway Shoulders:
The use of lateral guidance to enable 2.7 m wide buses to operate on 3 m wide bus-only freeway shoulders is the main focus of the ITS Institute's Bus Rapid Transit (BRT) project. In the longer term, this driver assistive technology is anticipated to evolve into automatic control of the vehicles.

Partners include Minnesota DOT and the Minneapolis-St Paul transit operator, Metro Transit. Currently, Metro Transit has 190 shoulder kilometers approved for BRT, with approximately 24 to 32 kilometers of approved shoulder kilometers added annually. Other partners to be added to this program include sensor technology developers and other transit properties; the objective is widespread deployment.

Sources:

1. Private Communication, Max Donath, March, 2001.
2. http://www.its.umn.edu/.

Twenty-First Century Truck (21T) Program
The 21st Century Truck Initiative (21T) is an emerging U.S. initiative fusing government, industry and academic interests in improving fuel efficiency, reducing emissions, increasing safety, and reducing the cost of ownership for the nation's light, medium and heavy duty commercial and military trucks. It was borne from the U.S. Army's response to the President's Global Change Policy, in which a plan was developed to create a multi-agency team, managed by the National Automotive Center, the dual-use automotive technology research organization for the Department of Defense (DoD). The program is conceived as a cost-shared industry/government partnership of organizations. Organizations with interest in 21T include: the Department of Energy (DOE), the Department of Transportation (U.S. DOT), the Environmental Protection Agency (EPA), virtually all U.S.-based truck original equipment manufacturers and engine suppliers, and various research and academic organizations (Southwest Research Center, Automotive Research Consortium, UC Berkeley PATH Program) (Sources: #s 1 and 2 listed at the end of this section).

As envisaged by the US Army, 21T was to have five interacting technology focus teams:
- Advanced Propulsion
- Alternative Fuels
- Advanced Materials
- Reduced Parasitic Losses
⟨ Vehicle Intelligence

The last item, Vehicle Intelligence, places AVCSS directly in the work plan for 21T. At present, the DOE has the "upper hand" in planning the program and it is likely that Vehicle Intelligence will receive lesser emphasis. In response, the US Army's National Automotive Center is considering creation of the Army Vehicle Intelligence Program (AVIP) (Sources: #s 3 and 4 listed at the end of this section). The Army's position is that AVIP will capitalize on other DoD programs, (e.g., DARPA's Demo II and III, Unmanned Ground Vehicle, Experimental Unmanned Vehicles), which provides for autonomous all-terrain operations, as well as the Army's Future Combat Systems initiative, which envisions robotic combatants on the battlefield (Source: #5 described at the end of this section).

There are at least five technical thrusts considered for the AVIP program (Source: #4 listed at end of this section):

- Examine US DOT's efforts in ITS for applicability to military domains, and to adopt those that are directly applicable. Collision avoidance and warning systems will be considered.
- Adapt selected ITS technologies and other "near-deployment" technologies for military applications.
- Develop AVCSS and other technologies that are currently not being aggressively addressed in the US by private industry, but of significant interest to the Army. This technology may include electronic tow bar and drive-by-wire technologies.
- Leverage the significant autonomous vehicle investment by the DoD.
- Expand the Army's Crewman's Associate concept for the development of a driver's associate, providing dynamic allocation of driving functions and enhanced situational awareness.

These thrusts may potentially translate to ten or more projects, envisioned to begin in early 2002, with funding level estimates varying from $2 – 15 million per year.

Sources:

1. Dennis Wend, Paul F. Skalny and David J. Gorsich, "Government-Industry Partnership for Improving the Military's and Nation's Trucks: The 21st Century Truck Initiative" in *National Automotive Center Technical Review, SAE Truck and Bus Edition 2000,* Portland OR, December 4 – 6, 2000.
2. James A. Misener and David J. Gorsich, "Vehicle Intelligence and the 21st Century Truck Initiative: A New Application for a New Century" in *Proceedings of the IEEE Intelligent Vehicles Symposium 2000*, Dearborn MI, October 3 – 5, 2000.
3. David J. Gorsich and Elio DiVito, "The Army's Vehicle Intelligence Program (AVIP): Bringing Telematics to the 21st Century Truck (21T)" in *National Automotive Center Technical Review, SAE Truck and Bus Edition 2000,* Portland OR, December 4 – 6, 2000.
4. Private Communication, Helmut (Bill) Knee, June 2001.
5. Private Communication, David J. Gorsich, June 2001.

Driver Condition Monitoring Systems
This section describes current and/or recent work in the area of driver condition monitoring systems.

Drowsy Driving Research:
One report focuses on explaining drowsy driving patterns and their links to crashes. The types of countermeasures listed are taking rest and rumble strips on highway shoulders. Concern is expressed about an alerting device that may provide a false sense of safety in the sense that driver will wait for the system to activate instead of taking a measure when they feel tired, so drivers would drive longer while being impaired by fatigue. A short mention of vehicle-based tools for measuring sleepiness is mentioned, brain wave monitors, eye closure monitors, and tracking devices for lane drifting detection. The report mentions that –at the time the report is being written- these systems still need more evaluation research to determine their efficiency.

Source: http://www.nhlbi.nih.gov/health/prof/sleep/drsy_drv.pdf ("Drowsy Driving and Automobile Crashes-Report and Recommendations", National Center on Sleep Disorders Research/National Highway Traffic Safety Administration Expert Panel on Driver Fatigue and Sleepiness, DOT HS 808 707 April 1998.

One section of a second report (Section 5) is devoted to driver alertness monitoring. The role of this type of device is to warning a driver during a trip (as opposed to systems activated at trip onset) of the degradation of his/her level of alertness. The device has to rely either on monitoring physiological cues (either remotely or through a device that the driver has to wear) or on assessing driver behavior. Guidelines for auditory, visual and tactile warning display are provided and several levels of warning are also discussed.

Source: "Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices" (DRAFT) - NHTSA Project No. DTNH22-91-C-07004 January 1996 - COMSIS Corporation http://www.itsa.org/federal.nsf/0/a6007f118454647e852565360046ce2d/$FILE/doths808342.pdf

A third report discusses an investigation of driver fatigue for Local/Short Haul practice in order to determine if it plays a role in crashes related to this type of operations. The results of this project will be guidelines for helping drivers to minimize the probability of being involved in an accident and recommendations about the amount of sleep at night and the length of shift.

Source: "Impact of Local/Short Haul Operations on Driver Fatigue", Wierville W., Virginia Tech Transportation Institute
http://www.vtti.vt.edu/index.cfm?fuseaction=DisplayResearchProjects&ProjectID=77

Driver Drowsiness Monitoring Systems:
SafeTRAC™ [1]is a vision-based lane tracking system, developed jointly by Assistware Technology, Inc. and Carnegie Mellon University under USDOT sponsorship. It is advertised as a Drowsy Driver Warning System and instantaneous lane departure warning. This system is composed of a micro video camera to monitor the road ahead. If the vehicle begins to drift off the road, or if it is weaving excessively due to driver drowsiness or some other impairment then it provides an audible warning to the driver. The warning threshold can be adjusted to trigger before or after the tire crosses the lane boundary. The system is being advertised as being usable in any type of vehicle (from light passenger vehicles to trucks). It is available now and the cost of the aftermarket version is $1975.
Source: http://www.assistware.com/page2.html

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[1] This system is also listed in the section about lane departure warning systems (Section 2.2.2.2).

Copilot is a monitoring system developed by Attention Technologies at the National Robotics Engineering Consortium (Robotic Institute of Carnegie Mellon University). Driver's drowsiness is measured via the analysis of slow eyelid closures and the proportion of time the eyes are closed. Drivers receive an auditory warning and can then check on a gauge representing their drowsiness level to decide which action to undertake. The technology used for this system is patented. The design phase of this system is completed. The current state of development is on extensive field-testing. Manufacturing and marketing are also issues being pursued at the present time. This system is sponsored by NHTSA and the FMCSA.
Source: http://www.rec.ri.cmu.edu/projects/copilot/copilot.shtml

Intersection Collision Warning Systems
The primary proposed effort addressing intersection collision warning systems in the United States is the proposed project, Intersection Decision Support (IDS). The focus is on vehicle-to-vehicle crossing path collision (which includes straight crossing paths, as well as turning movements). Signalized urban intersections are addressed in addition to rural intersections, most of which are not signalized. This is the ITS Joint Project Office's primary follow-on to the autonomous (e.g., subject vehicle-based) intersection collision avoidance requirements investigation conducted by Veridian Engineering under sponsorship by the National Highway Traffic Safety Administration (Source 1 at end of section).

The IDS program has enlisted as key participants the three State DOTs, the University of California PATH program, the University of Minnesota ITS Institute, and Virginia Polytechnic Transportation Institute. Caltrans has is the IDS lead. Currently, the USDOT has provided feedback on the proposal, and the IC is iterating on technical details with the support of its supporting universities (Source 2 at end of section). Some of that detail includes:
- Further definition of project detail
- A work element aimed at including automotive OEMs should the be interested (although a Tier 1 supplier, Visteon Corporation, is currently in the effort) and
- Provision of a mid-2003 demonstration of how a relatively near term IDS system would perform.

Award is anticipated in September 2001 at the latest (Source 3 at end of section).

The four basic tenets of IDS are:
- Application of system engineering principles of needs assessment, requirements generation, design driven by requirements, and experimental requirements validation.
- Development of a nationally interoperable architecture.
- Development of specific "solution sets" for real intersections.
- At the end of three years, pursuit of up to three demonstrations at real intersections of specific "flavors" of IDS – demonstrations that could each be readily and easily converted to a Field Operational Test.

These result in nine program tasks, A – I:
    A: Delineate the Intersection Crash Problem
    B: Develop Top Level Requirements for Types/Classes of Intersection Crashes
    C: Conduct Enabling Research & Development
    D: Prioritize Classes of Intersection Crashes for Initial Study
    E: Conduct Countermeasure Trade-off Analyses

F: Develop Detailed Requirements and Specifications for Each
       Countermeasure/Crash Class
G: System Design and Development
H: Conduct Subsystem Tests and Experiments
I: Prepare for Countermeasure Demonstration

Within these tasks are embedded the following research and development topics:
- Intersection science (i.e., driver actions at intersections)
- Surveillance technology
- Human factors
- Wireless communication
- System architecture
- Design and implementation
- Evaluation and validation
- Driver behavior models
- Cost-benefit and trade-off analysis
- Evaluation of commercial-off-the-shelf technologies.

Specific focus areas of the three states involved are:

The California focus is one of integration. The point of view is that the national problem is the California problem because of the State's diversity. Hence, California's portion of IDS includes extensibility and generality of specific approaches that may come from Minnesota and Virginia. The majority of the technical work will be performed by PATH, and the primary subcontractor to PATH is Visteon, a major Tier 1 automotive supplier and 3M as a secondary subcontractor. Technology foci of the California effort include vehicle-vehicle and vehicle-roadway communication, naturalistic driving collection and ensuing decision models, VMS-based infrastructure notification of drivers, and the application of a systems process.

Minnesota will focus on rural intersection crashes in all their forms through the application of a suite of advanced surveillance technology, collision predictive algorithms based on computational geometric techniques, and driver interfaces designed to best provide necessary information to drivers at intersections. The key deliverable will be a demonstration at an actual rural intersection of a system that can be deployed nationally on rural roadways.

Virginia is interested in developing techniques that solve the issue of straight crossing path crashes. The effort includes Virginia Tech Transportation Institute and the Virginia Transportation Research Council to conduct a series of tests on the Virginia Smart Road to develop the system architecture, system components, algorithm and driver interface for infrastructure cooperative intersection crash avoidance systems (The Smart Road is a controlled test facility that will allow testing to take place in a flexible and safe environment). The testing would be structured to support the eventual field-testing of cooperative systems to mitigate *Signalized Intersection, Straight-Crossing-Path Crashes* and *Unsignalized Intersection, Straight-Crossing-Path Crashes.*

Sources:

1. U.S. Department of Transportation National Highway Traffic Safety Administration, *Intersection Collision Avoidance Using ITS Countermeasures -- Task 9: Final Report:*

Intersection Collision Avoidance System Performance Guidelines, DOT HS 809 171 EDL #13341, January, 2001.

1. Freeman, K., "Intersection Decision Support" panel presentation in *Cooperative Vehicle Highway Systems, 11th Annual Meeting of the Intelligent Transportation Society of America*, Miami, Florida, June 7, 2001.

2. Ferlis, R., "Cross Cutting" panel presentation in *Intelligent Vehicle Initiative Updates, 11th Annual Meeting of the Intelligent Transportation Society of America*, Miami, Florida, June 4, 2001.

Private Sector Product Developments

The private sector developments are becoming more difficult to segregate by continent because of the global character of the automotive industry. So, some of the items identified here are likely to have overlap with European and Japanese activities.

Adaptive Cruise Control (ACC)

The passenger car products that are currently on the market in the U.S. are all on imported vehicles rather than domestically produced vehicles. However, one of the major ACC products on the market in Europe (for the Jaguar XKR) was developed by a U.S. supplier (Delphi). The U.S. should be a more fertile market for these than either Japan or Europe because of the large amount of highway driving and high market penetration of automatic transmissions.

- Mercedes S-Class (ADC radar-based system)
- Lexus LS-430 (Toyota Celsior – laser-based)
- Infiniti Q45 (Nissan Cima – coming to U.S. in summer of 2001 and laser (near-infrared) radar-based)
- Eaton-Vorad EVT-300 for heavy trucks (monopulse millimeter-wave Doppler radar) (Source: http://www.eaton.com/VORAD/)
- Delphi Automotive Systems supplied the ACC to Jaguar in Europe and is aggressively marketing to other automotive OEMs
- Visteon Automotive Systems is teamed with Autocruise (Thomson CSF, Lucas) on development of a competing ACC system

Lane Departure Warning Systems (LDWS)

The main developments are focused on use of video image-processing systems on heavy trucks that drive long distances, rather than on passenger cars.

- AssistWare Technology is supplying their SafeTRAC system to truck OEMs and also as an after-market retrofit to trucks for a price of $1975. It is being marketed as a drowsy driver warning system because it includes software to assess degradations in driving performance (drifting within the lane), not just lane departures. (Source: http://www.assistware.com)
- Iteris is supplying their Autovue system, developed in cooperation with DaimlerChrysler in Germany, to truck OEMs as well. They have also reached an agreement with Ford to supply a system for passenger cars if the results of testing and market evaluations are favorable. Their Web site claims that their algorithms are proven for European road conditions, but still under refinement for North American conditions. (Source: http://www.iteris.com)

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- The 3M Corporation independently developed a lane departure warning system based on use of a magnetized road marking tape and magnetic sensors mounted on a vehicle. This system was designed to provide a visual display of lane deviation as well as audible and haptic warnings to represent a "virtual rumble strip" to the driver who is drifting out of the lane. At the end of 2000, 3M announced the termination of their attempts to develop and market this system, although they may still be willing to sell the magnetized road marking tape to customers who request it. Despite its use in the Minnesota operational test of snowplow guidance under the federal IVI program, the market for this technology did not develop quickly enough to sustain the company's interest.

Side-Obstacle Warning Systems (SOWS)
Delphi Automotive Systems marketed a system for use on school buses under their "Forewarn" brand name, but it does not seem to have been a market success. The only currently commercialized systems are for use on heavy vehicles (trucks and buses).

- Eaton-Vorad EVT-300 system includes a 10 GHz radar side warning for the truck-tractor (but not the trailer)
- Collision Avoidance Systems, Inc. has supplied an ultrasonic system for testing on one hundred buses in Pittsburgh under the IVI program. It is based on a product (called Blind Sight) they originally developed for trucks, with a range of about 2 m to detect other vehicles.
- A variety of other small companies are marketing simple retrofit systems for installation on trucks and buses, providing proximity warnings.

These systems have been implemented as simple proximity detectors. As a consequence, they are vulnerable to nuisance alarm problems associated with rain, road spray and adjacent guardrails.

Maneuvering Aids for Low-Speed Operation (MALSO)
These parking assistance systems are available on a variety of high-end imported cars, such as Mercedes and BMW, as well as a variety of Ford vehicles. However, these have limited applicability as safety systems because of their very limited sensor range. Longer-range backup warning systems are under development by a variety of suppliers (including Delphi Automotive Systems) to meet the more demanding requirements for higher-speed backing maneuvers common in the U.S.

Forward Vehicle Collision Warning Systems (FVCWS)
These systems are not yet available in the U.S. passenger car market because of concerns that the technology is still far from being ready, particularly with regard to avoidance of nuisance alerts. The Eaton-Vorad EVT-300 provides this capability using 24 GHz radar for heavy trucks, whose drivers are thought to be more tolerant of what Eaton-Vorad likes to call "reassurance alarms". (Source: http://www.eaton.com/VORAD/) Altra Technologies has a radar-based forward collision warning system as well, which they are supplying to the IVI test of snowplows in Minnesota.

These are troublesome because these systems need to be able to detect stopped obstacles (such as other vehicles) in an environment complicated by many clutter sources, such as bridges, signs, guardrails and other features of the roadway infrastructure. The current technology is not

good enough to readily distinguish these kinds of clutter from the stopped vehicles that the systems must detect, so the systems tend to issue alerts even in the absence of real hazards. Since real hazards are relatively infrequent, this raises the likelihood that drivers will ignore the alerts for those hazards or will deactivate the systems entirely.

Night Vision Enhancement Systems

General Motors has introduced a system on its Cadillac De Ville, using an infrared system supplied by Raytheon, based on technology originally developed by Texas Instruments. This costly option has been more popular than expected with the predominantly elderly purchasers of this luxury car. It is particularly effective at highlighting pedestrians and animals at night in rural areas, where the roads are not illuminated. The system does not issue any alerts to the driver, but simply provides the infrared image of the forward scene on a head-up display for the driver to look at if he or she so chooses.

Driver Condition Monitoring Systems

Ford: Driver Alertness Monitoring is mentioned as one of their Ford's "Next Wave Technologies", with deployment in the "near future". Driver alertness monitoring would address driver's ability impairment due to either inattention or drowsiness with simple a system, which would sound an alarm. More complex systems for warning drivers of impending collisions might also be considered.
Source:
http://www.itsa.org/85256201003EFA03/0/279F2231ACA3CCEC8525686A006E997E?Open&Highlight=2,drowsiness (Page last updated on Tuesday, January 18, 2000)

TRW and Biosys: TRW Inc. and Biosys AB of Goteborg, Sweden, announced today that they have signed an agreement for the marketing and development of a slumber warning system to alert vehicle drivers to conditions of drowsiness. The two companies will work together to market and develop an automotive application, using Biosys technology that notifies a driver when he or she becomes too tired or drowsy to operate the vehicle safely. The Biosys system, which is expected to consist of a sensor mounted in the driver seat, can be adapted for all types of vehicles.
Source: From the Intelligent Transportation Society of America Web site:
http://www.itsa.org/85256201003EFA03/0/1596A6E5E4466A8B8525679E006796AC?Open&Highlight=2,drowsiness

Kenworth Truck Company: A driver's drowsiness monitor that tracks driver performance to keep the vehicle in its lane and gives an alertness rating based on that performance is to be implemented on the company's T2000 High-Tech Truck.
Source:
http://www.itsa.org/85256201003EFA03/0/DF18F0A09D640C53852568AA0069074A?Open&Highlight=2,drowsines Page last updated on Wednesday, March 22, 2000

Johnson Controls: The Driver-Drowsiness Alert System uses vehicle-mounted sensors and a microprocessor to learn and monitor driver behavior and deliver a warning when the driver begins to nod off. A variety of alert signals can be used, including lights, sound and/or seat vibration.

Source:

4.1.3 Demonstrations of Technologies and Advanced Vehicle Control and Safety Systems

Demo '97
This event was a four-day demonstration on the High Occupancy Vehicle freeway lanes of Interstate 15 in San Diego, California that tested automated control capabilities of cars, trucks, and buses with both driving and static demonstrations. The event was part of the work of the National Automated Highway Systems Consortium. Seven different scenarios were shown, including

- Free-Agent, Multi-Platform Scenario: Vehicle-based technologies were used across different vehicle platforms with two buses, one minivan and two passenger cars showcasing obstacle avoidance and collision warning, lane change maneuvers, and an operator/driver interface.
- Platooning Scenario: Eight specially equipped light-duty passenger vehicles traveled in a single-file formation guided by roadway-imbedded magnets. In platoon formation, they accelerated, decelerated, performed a coordinated stop, split into two sub-platoons to allow other vehicles to enter and then rejoin as one platoon. Drivers received information such as vehicle speed, current maneuver and distance to destination via a head-up display.
- Commercial Truck Scenario: One tractor-trailer truck and one passenger car were used on the highway lanes. The truck followed the car at a constant timegap while the car changed speed several times and issued a forward collision warning when the car cut in front of it. The truck also had a blind-spot warning system on board.
- Maintenance Scenario: Automated maintenance operations were shown using two vehicles, one of which was equipped with autonomous lateral control equipment and conventional cruise control as well as diagnostic equipment to conduct monitoring, physical inspection, and preventative care—all while traveling under automated control at highway speeds. Another vehicle demonstrated the automatic removal of debris from the AHS lanes.
- Control Transition Scenario: Two approaches were shown—an infrastructure-supported approach and an independent vehicle approach. Two specially equipped light-duty passenger vehicles were used to demonstrate platooning capabilities while transitioning between two modes of lateral control (infrastructure-supported and independent vehicle control). Laser technology was used for longitudinal control in both cases.
- Alternative Technology Scenario: As an alternative technology for lateral control, radar-reflective tape was used in conjunction with a single camera-based vision system. In addition, a low-powered radar system was used for side vehicle detection and a laser system was used for longitudinal control.
- Evolutionary Scenario: The emphasis was on the evolutionary nature of vehicle automation to demonstrate lane departure warning, obstacle detection warning, longitudinal control using intelligent cruise control, automated lateral control using a

vision system, obstacle avoidance using laser detection and automated lane change maneuvers.

Demo '99
This event held at the Transportation Research Center's test track in Ohio, was an Intelligent Transportation Society of America event with vehicle demonstrations (on a test track with a realistic highway environment) of emerging vehicle systems for safety and productivity, based on advanced sensor and control technologies, including adaptive cruise control, collision warning and avoidance, driver impairment detection, stability control, lane sensing, precision maneuvering assistance, rear impact countermeasures, and automatic collision notification. Vehicle manufacturers, suppliers, technology firms, and research institutes attended to showcase systems operating on cars, heavy trucks, buses, and specialized vehicles, including cooperative vehicle-highway applications. The purpose was to enlighten the public and transportation professionals as to the maturity of these vehicle systems and the diversity of applications (cars, trucks, buses, and other vehicles), thus creating support and preparing the future market.

IVI Technology Showcase 2000
The National IVI (Intelligent Vehicle Initiative) Meeting was held in July 2000 in Washington, D.C. to showcase accomplishments in intelligent vehicle technologies and highlight the achievements of government and industry partnerships; to serve as a forum to validate current and future directions of IVI-related research and development; and to promote public/stakeholder awareness of efforts to improve traffic safety by developing intelligent vehicle technologies.

Driving demonstrations included the following:

- Lane departure warning and intersection collision warning systems were featured on light-duty passenger vehicles
- Lateral guidance, rear-end collision warning, rear-impact collision warning, and a heads-up display were featured on a specialty vehicle—a snowplow.
- Rollover stability control/advisor, infrastructure-assisted hazard warning system, automatic collision notification, lane departure warning system, adaptive cruise control, collision warning, and advanced braking were featured on commercial vehicles.

Static displays showcased the following systems:

- Rear-end collision warning and avoidance
- Adaptive cruise control
- Lane change/merge collision warning
- Night vision
- Heads-up display
- Reconfigurable dashboard
- Onboard data collection
- Side collision warning

Demo 2003
The California PATH Program and the California Department of Transportation (Caltrans) are planning to showcase fully automated buses and trucks on the HOV freeway lanes of Interstate

15 in San Diego in August 2003. The demonstration will showcase Advanced Vehicle Control and Safety System technologies in the context of bus rapid transit and automated freight transport services supported by these technologies. The demonstration will include three Class 8 ("eighteen wheeler") trucks and two 12 m single unit and one 18 m articulated transit buses, operating in full automation and driver assist modes. The vehicles being developed will have full automation capability, meaning computer controllable steering, fuel delivery, and braking. In addition to these actuators, a sensor suite and control computer will be integrated into each vehicle to allow full lateral and longitudinal automation. The purpose of this demonstration is to show the viability of heavy vehicles as early users of advanced vehicle control and safety system (AVCSS) technology. Numerous scenarios are under development including full automation with platooning, lane changes, and merge, split, and join maneuvers and automated precision vehicle docking. Additional information may be obtained from the Web site source: http://www.demo2003.org as it becomes available.

IVI 2003
Another IVI Program-related showcase of IVI technologies and systems is being planned for 2003.

4.2 Japan

4.2.1 Institutional Context: Overview of Government Roles
Japan has highly centralized government decision-making on most issues of national importance, at least as centralized as the most centralized of European countries. The regional (prefectural) and local (city) governments generally have much less influence than the national government. There is a strong tradition of cooperation between government and industry, particularly with the very large companies and groups of companies (keiretsu) that dominate the Japanese economy.

Five government ministries have had roles in the Intelligent Transportation Systems (ITS) industry:

- National Police Agency (NPA) is responsible for traffic management in all of the cities
- Ministry of Post and Telecommunications (MPT) is responsible for development and regulation of wireless communications systems
- Ministry of Construction (MOC) is responsible for development and operation of all public infrastructure (highways and bridges as well as water and waste management)
- Ministry of Transport (MOT) is responsible for regulating safety of road vehicles
- Ministry of International Trade and Industry (MITI) is responsible for promoting international competitiveness of Japanese industry and is also the protector of the automotive industry.

The latter three have responsibilities relevant to Advanced Vehicle Control and Safety Systems (AVCSS) technologies, so they are the only ones that will be considered further here. In January 2001, the entire Japanese government was restructured. As part of this process, the MOC and MOT were merged with some other agencies into the new Ministry of Land, Infrastructure and Transport (MLIT) and MITI was combined with others into the new Ministry of the Economy, Trade and Industry (METI).

It is important to understand the distinct character of these Ministries in order to see how ITS has developed in Japan. The Ministries invest considerable energy in competing with each other. Industry and academic people need to be careful to maintain cordial relationships with these rival ministries. The rivalries among the ministries can lead to inefficiencies and duplications of effort.

Ministry of Construction (MOC)
This ministry is one of the most powerful and wealthiest ministries in Japan, and also one of the most outward- looking. It is viewed as an engine of economic growth, and its investments in public works are often targeted toward stimulating the economy as well as meeting specific transportation needs. One can readily see the evidence of its huge investments simply by traveling around Japan and observing the massive scale of its bridge, tunnel and highway construction.

Importantly for ITS, the MOC has realized that its civil infrastructure is now largely "built out", and the country is nearly completely supplied with the highways, bridges and tunnels that it needs to tie its people together. In places where additional road capacity is still really needed (major urban areas), the environmental and quality of life considerations make it politically impossible to do much more construction (except for phenomenally expensive underground highways). So, the MOC has searched for other outlets by which to invest its resources. Equipping the roadway infrastructure with ITS electronics has therefore been seen by MOC as a major part of its new mission.

The MOC was the sponsor of the "AHS" program and the public-private partnership "AHSRA". The Japanese AHS (then Automated Highway System) program was initiated in 1995 as a direct response to the creation of the NAHSC (National Automated Highway System Consortium) in the United States. They conducted demonstrations of automated vehicles at their Public Works Research Institute (PWRI) in 1995 and on a stretch of unopened public highway in 1996, based on concepts of coordinated platoons of vehicles following magnetic markers in the pavement, adopted from prior work at PATH in the United States (See Sections 3.1.1 and 3.1.2). However, in 1997, when the USDOT began to back away from AHS and automation, MOC followed quickly and changed the definition of AHS to "Advanced Cruise-Assist Highway System" in Japan, which is how it remains today. This is intended to emphasize the use of AVCSS technologies to provide information, warnings and control assistance to drivers, with automated driving being defined more vaguely for the future.

The MOC work on "AHS" has emphasized the development of the electronic infrastructure to interact with suitably equipped vehicles, because this ministry is responsible for infrastructure and not for vehicles. They have strong relationships with the major electronics companies that provide infrastructure electronics, and have brought them into their program as strong partners, probably with some financial incentives. The vehicle industry has been a more reluctant partner. The general tendency for the MOC has been to promote infrastructure electronics that are more costly than other countries would consider installing, because they have traditionally had a very large budget. They have been very active in bringing their infrastructure systems forward in ISO for international standardization, to help build a stronger market for their industrial partners.

MOC was the major organizer of the "SmartCruise21" Demo 2000 in November/December 2000, and was by far the most visible promoter of it on the international scene (See Section 3.1.3). Their part of this Demo focused almost entirely on the use of infrastructure-based

sensing and communication devices ("SmartWay"). This included widespread application of the DSRC technology that they have recently standardized for electronic toll collection in Japan to communicate safety information from roadside to vehicles.

PWRI, the research arm of MOC, has established a strong international presence in ITS. They have bilateral agreements with the Federal Highway Administration in the U.S. and with the Highways Agency in the UK, under which they exchange staff members on a rotating basis. This provides them with sources of information in other parts of the world, as well as opportunities to communicate their ideas directly to their counterparts in other countries.

Ministry of Transport (MOT)
This Ministry is much more inward-looking than the others discussed here, and rarely participates in international contacts. Its jurisdiction is more narrowly focused on safety regulation of the vehicle industry, which needs to pay close attention to its interests.

The major relevant program within MOT is the Advanced Safety Vehicle (ASV), which is in some sense analogous to the IVI program in the U.S. Under the auspices of ASV, all of the major Japanese automotive OEMs have been developing a wide variety of advanced technologies to enhance safety. These have included ITS technologies for warning and control assistance, but have extended far beyond ITS as well, to include external airbags to protect pedestrians, airbags for motorcycles, water repellent windshields, etc. Very importantly, these development activities are not funded by the MOT, but are funded directly by the companies themselves, with MOT providing guidance and coordination. It is not clear whether the companies retain full proprietary rights to their developments or whether they are pushed to share some of their safety technologies with their competitors.

There is very little documentation of the ASV program existing in English. Some of the prototype vehicles developed under this program have been exhibited by the individual companies at international conferences and some papers have been presented as well, again directly under company sponsorship. ASV was the basis for a major part of the SmartCruise21 Demo 2000, with vehicle demonstrations at the Japan Automobile Research Institute (JARI) test track. This part of the demonstration was almost invisible to international visitors, but it actually contained more advanced technologies and more impressive capabilities than the demos at PWRI (where the international visitors were concentrated).

Because of jurisdictional and ideological considerations, the ASV systems were all based on autonomous vehicle sensing technologies, with no cooperation with the infrastructure or other vehicles. These technologies are highly sophisticated and innovative, comparable to or ahead of the leading technologies in Europe and North America.

Ministry of International Trade and Industry (MITI)
This ministry is the main proponent of Japanese industrial and economic strength, and its mission is not specifically focused on transportation issues. However, it is the special protector of the automotive industry. Its Mechanical Engineering Laboratory (MEL) has been conducting sophisticated and visionary research on vehicle automation technology since the 1960s, mainly under the leadership of Dr. Sadayuki Tsugawa. Because of this laboratory's interests in robotics and factory automation, many of the technical approaches have strong roots in those fields.

MITI has made only modest investments in ITS compared to the other two ministries, and much of its work has been in long-term conceptual studies and small-scale laboratory experiments. However, it has also conducted some experiments on full-scale automobiles, with an emphasis on fully automated driving on automated highways, and a second emphasis on development of extremely small and lightweight urban vehicles.

MITI's MEL held a Demo 2000 demonstration immediately prior to the larger Demo 2000 of the other two Ministries. This demonstration was of a "flexible platoon" of automated vehicles using high-accuracy DGPS for positioning and vehicle-vehicle communications to coordinate maneuvering. It was thus completely complementary to the other two demonstrations by eschewing both vehicle-infrastructure cooperation (MOC) and vehicle-based sensing (MOT).

Summary
The fragmented development of three disjoint demonstrations for Demo 2000 was perfectly emblematic of the primary weakness of the Japanese system – the deep-seated rivalries among its government ministries. If they can overcome this and combine the three disjoint approaches to AVCSS technologies, they could accomplish great things. The merger of MOC and MOT into MLIT will be a first test to see whether these rivalries can be overcome.

4.2.2   Advanced Vehicle Control and Safety Systems

Government/Public Sector Projects
The government/public sector projects are separate and largely competing programs with very different orientations that are determined by the missions and interests of their different government sponsors.

Advanced Safety Vehicle (ASV)
The Ministry of Transport (MOT), now merged into Ministry of Land, Infrastructure and Transport (MLIT), has promoted research and development for the last ten years on the Advanced Safety Vehicle (Source: *Advanced Safety Vehicle: Achievements of Promotion in ASV Phase 2 (ASV-2)*, MOT Study Group for Promotion of ASV, 2000, Japan). The project has been divided into two phases with ASV-1 (1991-1995) and ASV-2 (1996-2000). ASV-1 focused on concept design, research on component and system technologies, development of a prototype vehicle and demonstration of this vehicle, while ASV-2 emphasized continued research on component and system technologies, production of test vehicles and demonstration of full-scale experiments. The ASV-2's thrust is on autonomous vehicle sensing for collision warning and avoidance. Research and development has progressed on all major vehicle types, including light-duty passenger vehicles, trucks, buses, and motorcycles and demonstrations have been made (Demo 2000). All major Japanese automotive manufacturers are participating in this program, including:

- Daihatsu (passenger cars, light-duty vans)
- Isuzu (trucks, buses)
- Hino (trucks, buses)
- Honda (passenger cars, motorcycles)
- Mazda (passenger cars)
- Mitsubishi (trucks, passenger cars)
- Nissan (trucks, passenger cars)
- Subaru (passenger cars, light-duty vans)

- Suzuki (trucks, motorcycles)
- Toyota (passenger cars)

Differences exist as to the specific types of systems that are being tested and deployed in individual ASVs by vehicle type and among the various automobile OEMs. However, the following common system threads include the following:

- Drowsy driver warning
- Side obstacle advisory/warning
- Lane departure prevention support
- Lane keeping assistance
- Forward obstacle collision prevention support
- Adaptive cruise control with brake control

Advanced Cruise-Assist Highway Systems (AHS)

The Ministry of Construction (MOC), now merged into the Ministry of Land, Infrastructure and Transport (MLIT), has promoted research and development into automated highway systems yet the focus of this research was changed in the mid-1990s to "Advanced Cruise-Assist Highway Systems". This change in focus was coupled with the formation of a public-private partnership between the MOC and private industry (representing electronics, automotive, heavy machinery, and telecommunications). This partnership organization is called Advanced Cruise-Assist Highway Systems Association (AHSRA) and focuses on infrastructure-based sensing and intelligence for collision warning and avoidance, with communication from infrastructure to vehicles (See Section 1.1.1). Major systems under research and development include the following seven user services:

1. Forward obstacle collision warning
2. Lane departure warning
3. Side impact/collision warning for right turns
4. Side impact/collision warning for cross-vehicular traffic
5. Side impact/collision warning for pedestrian traffic
6. Roadway curvature information and warning
7. Roadway surface condition warning

Demonstrations of these systems have been at Demo 2000 in Tsukuba City, Japan (See Section 3.1.3). (Source: *Outline of Advanced Cruise-Assist Highway Systems*, Public Works Research Institute, Ministry of Construction, November 2000 and http://www.ahsra.or.jp/)

Super-Smart Vehicle Systems (SSVS)

The Ministry of International Trade and Industry (MITI), now merged into Ministry of Economy, Trade and Industry (METI), is promoting work on the SSVS. There is no infrastructure and only minimal in-vehicle sensing. The focus is on the use of Differential Global Positioning Systems (DGPS) and vehicle-vehicle communication for coordination of vehicle control, emphasis on fully automated vehicle operations. It aims at raising the safety, comfort, and efficiency of motor vehicle traffic by adding sophisticated functions such as environment recognition and danger avoidance functions, traveling information exchange functions, and traffic flow control functions. At present, R&D on communications between vehicles is being conducted by focusing on situational awareness and recognition, information exchange, and

information processing on vehicles. It also includes intersection surveillance and traffic monitoring techniques for smoothing traffic flow.

University Research Projects
These are generally small projects at a few universities[2] some of which participated in Demo 2000 in Japan. Examples of research topic areas include the following. The primary source of information for university-related research topics is the *Proceedings of the IEEE Intelligent Vehicles Symposium 2001 IV2001*, National Institute of Informatics, Tokyo, Japan, June 2001. While this list may not be exhaustive, nevertheless, academic institutions play only a small role in AVCSS-type of research relative to private industry contributions.

- Automatic recognition of roadway signs
- Development of supervisory system architecture for vehicular traffic operating conditions
- Vehicle position recognition system
- Automated steering systems based on model reference control
- Intelligent vehicle idling system
- Autonomous vehicle control for specialty vehicles (agricultural vehicle application)
- Vehicle-vehicle, roadside-vehicle communications

Driver Condition Monitoring Systems
Work conducted in the context of the Advanced Safety Vehicle (See Section 2.1.1.1) includes the following:

Driver's drowsiness has to be detected to help prevent collisions or lane departure type of accidents. The functions of the system aim at detecting driver's arousal or inattention. The detection is operated either by vehicle's behavior or driver's facial expression monitoring. The system provides warning or information about the situation. Studies are underway for the evaluation of stimulating driver's arousal with vibration or smell.

Source: Brochure from Demo 2000 (Tsukuba Japan) Advanced Safety Vehicle (ASV): "Achievements of Promotion in ASV Phase 2 (1996 ~ 2000)".

The drowsiness advisory system uses driver's face for detecting the eyelid pattern. Driver's drowsiness is measured through the frequency of eye blinks and slow eye closure. When drowsiness is detected, a buzzing sound or vibrations through the seat are emitted.

Source: Brochure from Demo 2000 (Tsukuba Japan) Advanced Safety Vehicle (ASV): "Nissan Diesel's ASV".

Infrastructure-based Speed Control
Infrastructure-based speed control work is being conducted in Japan under the auspices of AHSRA. AHSRA (See Sections 1.1.1 and 2.1.1.2) is sponsoring research, development, testing, and evaluation of numerous systems under its Smart Cruise Systems program. Driver behavior is grouped into longitudinal, lateral, and intersection elements. Corresponding to these three types of driver behavior are principal user services most closely associated with providing assistance to each of these behavioral types:

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[2] University of Tokyo, Seikei University, Keio University, Kobe University, Nihon University, Ryukoku University, Science University of Tokyo, Yokohama National University.

The user services that can influence the longitudinal behavior of drivers, in other words, with the most potential to have an impact on the vehicle's speed include:

To improve safety:
    1. Maintenance of safe headway
To improve efficiency and the environment
    1. Maintaining suitable headway
    2. Reduction of headway
    3. Optimum speed

AHSRA's "cruise assistance" method by each user service is executed by means of three driver support functions described below in increasing amounts of vehicle-infrastructure automation:

Function 1:   Information provided to driver to avert hazardous and/or dangerous situations
Function 2:   Warning will be given if the driver does not respond to information from Function 1
Function 3:   Operational support, i.e., intervention by the system if driver does not heed warnings given in Function 2.

These three stages are analogous to the three variants of the European Intelligent Speed Adaptation system.

Sources: "Outline of Advanced Cruise-Assist Highway Systems", November 2000, Public Works Research Institute (PWRI), Ministry of Construction.
Advanced Cruise-Assist Highway System Research Association, http://www.ahsra.or.jp/

Intersection Collision Warning Systems
There are two distinct Intersection Collision Warning (ICW) efforts in Japan:
   • The Advanced Cruise-Assist Highway System Research Association "SmartCruise 21" effort, reported in Demo 2000, under the auspices the Ministry of Land, Infrastructure and Transport (MLIT).
   • The Driving Safety Support System (DSSS), sponsored by the National Police Agency (NPA).

SmartCruise 21 ICW:
The SmartCruise system demonstrated in the Tsukuba City test track demonstrated the following three user services (See Sources 1 and 2 at end of Section.):
   • Straight crossing collisions, particularly when approaching vehicles stop and restart
   • Right turn collisions (keeping in mind that Japanese drive on the left hand side of the roadway), and
   • Vehicle-pedestrian collisions.

The basic four-part sequence is *sensing + threat assessment + communication + warning* (Source 3). *Sensing* is accomplished at the roadside, be it downstream for vehicle trajectory estimation or along the crosswalk for pedestrian detection. *Threat assessment* is also made on the roadside. *Communication* of perceived threats occurs via an experimental 5.8 GHz dedicated short-range communications (DSRC) link. The warning is always in-vehicle and may prompt driver action.

As we understand, there are several prototype technologies being considered for each part of the sequence. For example, sensors may be visible imaging, infrared imaging, millimeter wave, or laser radar (Source 3).

Driving Safety Support System (DSSS):
This NPA-sponsored system is different than the MLIT system. The DSSS prototype, demonstrated in the Fall of 2000, is the result of an NPA collaboration with the Universal Traffic Management Society (UTMS) of Japan. Although many of the technologies are the same, a key difference between the UTMS and AHSRA approaches is that in the UTMS approach, a two-way communication card will be necessary for subscribers of the service (Source 4). Hence, in the UTMS approach the card carried by an elderly driver or pedestrian will invoke the DSSS.

In the DSSS, four services (or in their parlance, "system functions") are addressed (Source 4):
- All crossing paths (Straight-, right- and left)
- As an explicit and specialized sub-category of straight-crossing path collisions, oncoming traffic, particularly where there is a curve or other occlusion near the intersection

Future system functions may include (Sources 5 and 6):
- Warning of impending traffic phasing
- Green light extension for pedestrians
- Infrastructure-mounted changeable message signs to warn drivers and pedestrians
- Installation at intersections that are not signal-controlled
- Head-on collisions
- Specific focus on warning motorcycle drivers.

Sources:

1. Advanced Cruise-Assist Highway System Research Association, *AHSRA Report, Vol. 7,* "Report on Smart Cruise 21 Demo 2000", May 2001.
2. Public Works Research Institute, Ministry of Construction, *Outline of Advanced Cruise-Assist Highway Systems,* November 2000, pp 35 – 41.
3. Advanced Cruise-Assist Highway System Research Association, *SmartCruise 21 Demo 2000 Panel Sessions/Technical Sessions Presentation Materials*, February 2001, pp 107-112.
4. Universal Traffic Management Society of Japan, *Demonstration of Driving Safety Support Systems*, January 11, 2000 (flyer)
5. Mikio Sugimoto, et al, "Realization of Head-on Collision Warning System at Intersections – DSSS: Driving Safety Support Systems" in *Proceedings of the IEEE Intelligent Vehicles Symposium 2000*, Dearborn MI, October 3 – 5, 2000.

Private Sector Product Developments
There is intense interest within the Japanese automotive OEMs and suppliers in developing and selling AVCSS capabilities. The Japanese domestic market is atypical of those in other industrialized countries in several ways that tend to pull in different directions:

- Because traffic conditions and density of development are so extreme in the major urban areas, most daily work trips are made by public transportation rather than by private car. Cars are used more for personal and leisure travel.
- There is a very limited network of motorways or highways where vehicles can operate for a sustained period of time without stopping for cross-traffic. These are toll facilities, with high toll levels.
- The vehicle buyers are very status-conscious and interested in adopting new gadgetry, even when it does not work very well. This is an advantage for the Japanese industry, because they can introduce products that would not be considered acceptable in maturity in other parts of the world.
- Japanese carmakers are willing to introduce innovative features that will not sell in large quantities, just so that they can claim bragging rights for first introduction of these features.
- Japanese government regulations force the turnover of the vehicle fleet within seven years or less, by making it prohibitive for vehicle owners to re-register vehicles that are more than seven years old. These used vehicles are then exported to other Asian markets.

Taken together, these factors encourage the introduction of new technologies by the Japanese motor vehicle industry. Even if these are not well suited for the driving conditions in Japan, they can gain operational experience with them and work out the bugs there before bringing them to other sectors of the world.

Adaptive Cruise Control (ACC)
Mitsubishi introduced the world's first production ACC in 1995, as a very expensive option (about $4000) on their top-of-the-line car. Very few were sold, and many of those were bought by their competitors so they could test it out. In that system and most introduced since then, the primary sensor choice has been laser radar, because it was considered cheap and a variety of suppliers had the capability of making it. However, these systems are very dependent on receiving specular reflections from clean retro-reflectors in the taillight assemblies of preceding vehicles. They perform poorly when those reflectors are dirty, and sometimes cannot even recognize the presence of a dirty car or truck.

There are indications of increased interest in millimeter wave radar sensors in Japan, but this is a technology in which they are not strong (based on lack of a defense industry). The original Japanese standard for this was at 60 GHz, but more recently they appear to be moving to 76-77 GHz for consistency with Europe and the U.S. Hitachi is developing a 77 GHz version of the Eaton-Vorad radar, for example.

- Mitsubishi Diamante's Preview-Distance Control (1995) – laser plus vision for lane identification
- Mitsubishi Proudia (2000) – laser plus vision
- Toyota Celsior and others – Denso laser
- Nissan Cima and other models – (In Japan a millimeter wave forward sensor is used while in the U.S. the Infiniti Q45 -the next generation- will be laser (near-infrared)) radar-based
- Honda (various models) – Omron laser
- Subaru Legacy Lancaster – stereo vision only

Lane Departure Warning Systems (LDWS)

These are all based on use of machine vision technology to recognize lane markings.

- Subaru Legacy Lancaster – stereovision
- Mitsubishi Proudia (2000)
- Nissan Cima (with addition of lane keeping assistance, 2001)

The new Nissan Cima represents another significant world "first", with its addition of active steering control assistance. This raises profound questions of driver engagement, because the same vehicle is equipped with ACC, making it possible for the driver to experience a simulacrum of automated driving. Both systems have serious performance limitations, making it possible for drivers to get into potentially dangerous situations.

Side-Obstacle Warning Systems (SOWS)

Mitsubishi Proudia (2000) has a warning system using a video camera mounted at the rear of the trunk lid, providing coverage behind the vehicle of approaching vehicles (but no visibility in the blind spot). This uses optical flow to detect threatening vehicles, based on original development by Toshiba, commercialized by Yazaki. It is intended as a lane-change assistance system for use in highway driving, and gives the driver a continuous schematic display (top-down view) of the traffic environment behind him, plus an audible warning of a threatening vehicle approaching if he activates his turn signal for a lane change. It does not give the driver a direct projection of the rear video image, which would be disorienting in this context.

Maneuvering Aids for Low-Speed Operation (MALSO)

These short-range ultrasonic sensor systems detect obstacles at very short range (typically 1 m or less) while parking in tight parking spaces. Denso has supplied a system to Toyota since at least 1995, and other OEMs have implemented systems from other suppliers as well. Because of their short range, these have essentially no applicability beyond the parking function.

The Nissan Cima has a rear-facing video camera in the trunk lid, the output of which can be displayed on the navigation display screen when the car is in reverse, providing the driver with a view of potential hazards behind the vehicle while parking.

Forward Vehicle Collision Warning Systems (FVCWS)

These systems are intended to detect stationary as well as moving vehicles ahead of the equipped vehicle. Laser-based systems have been sold in limited quantities, by the truck manufacturers Hino (Toyota) and Nissan Diesel. However, these systems are limited in their capabilities by the difficulty of distinguishing "real" target threats (stopped vehicles, dropped loads) from the "clutter" represented by normal parts of the driving environment (overhead bridges, signs, lighting fixtures, guard rails, etc.).

Fully Automated Driving

Toyota Intelligent Multimode Transit System (IMTS) using automated mid-size buses is being tested on test tracks and is planned for use at the new Nagoya International Airport and an international exposition near Nagoya in 2005. It may be implemented elsewhere earlier than that, but information on that is difficult to find. It uses magnetic markers as the lateral control reference and laser radar combined with wireless communications for longitudinal control. It has

been demonstrated in test-track operation at moderate speeds with a three-vehicle automated platoon, providing smooth and accurate response.

Toyota "e-com" two-seater electric cars have been providing an automated "drive" for visitors at the Toyota Mega Web amusement park in the Odaiba district of Tokyo since early 1999. This covers a loop of about 1 km at a speed up to 15 km/hr. Visitors can sit in the "driver's seat" while the car drives itself around the track, which is physically isolated from all intrusions by Plexiglas panels and metal railings. Magnetic markers provide the lateral control reference, but the longitudinal control appears to be implemented by a more conventional moving-block system rather than any kind of active vehicle following. The separations between vehicles are quite large, limited to some extent by passenger loading and unloading at the stations, which are on the mainline track.

Honda's Intelligent Community Vehicle System (ICVS) two-seater electric cars are used at the Motegi development north of Tokyo, where Honda has a racetrack and museum. These vehicles can drive and park themselves under automatic control, and have been designed to include an "electronic tow-bar" capability for moving groups of vehicles to locations where customers need them, but it is not clear how available they are for rides by members of the general public.

Automated trucks are of significant interest in Japan and have been researched and tested, but some political controversies appear to have slowed their deployment. They were being planned for use on special truck lanes on the New Tomei Expressway, but that idea appears to have been put on hold.

Driver Condition Monitoring Systems
Hino proposes a drowsiness warning system with a vibrating seat. More information can be found at the Web site: http://www.hino.co.jp/index_e.html, however, it requires some Japanese reading proficiency.

Nissan proposes a drowsy/inattentive driving warning system. This system is based on facial images analysis. It detects drowsy driving by the identification of an eye closure pattern characteristic of a reduction in alertness. Inattentive driving is detected via the eye's position; the system determines if the eye is where it should be. Warnings are issued when the driver's face is clearly not facing the road ahead.

Subaru proposes a drowsiness warning system with an auditory signal. No supplementary information found on Web site http://www.subaru.com/

Mitsubishi proposes a driver alertness monitor. Blinking frequency and eyelids closure times are the cue used by the system. The system issues a voice and visual warning to the driver. More information available at http://www.mitsubishielectric.com/pdf/advance/vol78/78tr6.pdf

Additional Sources: Brochures available and distributed at Demo 2000 in Tsukuba Japan.

4.2.3 Demonstrations of Technologies and Advanced Vehicle Control and Safety Systems

AHS Demonstration Tests 1995
In November 1995, the PWRI of the Ministry of Construction together with private industry partners in the automobile and electronic engineering industries put on this demonstration on the PWRI Test Track in Tsukuba, Japan. Tests were conducted using nine test vehicles for automated driving and five test vehicles for a roadway incident detection and warning system. The demonstrations tested basic technologies in adaptive cruise control (acceleration and braking control) and the capabilities of the roadway incident detection and warning system to detect and identify stalled vehicles on the roadway resulting from accidents and fallen objects or debris with roadside sensors. Additional information may be obtained from the Web site source: http://www.netpark.or.jp/ahs/eng/c08e/demo01.htm

AHS Operational Demonstration Tests 1996
In September 1996 the PWRI of the Ministry of Construction together with private industry partners put on this demonstration on the Joshinetsu Expressway in Komoro, Japan. Its objectives were to extend the types of driving maneuvers performed during the 1995 Demo on a real-road environment. Test facilities were set up on a new expressway before its opening to test the feasibility of AHS using eleven light-duty passenger vehicles. Key Demo features included tests of vehicle control on roads involving lateral and longitudinal inclines, the relationship between in-vehicle devices and various external disturbances such as power lines and overpasses, adaptive cruise control, platoon formation driving, longitudinal control (speed and braking control), lane departure warning using magnetic lane markers embedded on the road, laser radar tracking control function for vehicle spacing in platoon operation, obstacle/roadway hazard detection using onboard laser radar, and incident detection and warning function using roadside sensors. Additional information may be obtained from the Web site source: http://www.netpark.or.jp/ahs/eng/c08e/demo02.htm

Smart Cruise 21 Demo 2000
In November 2000, Japan's Ministry of Transport and the Ministry of Construction jointly conducted this demonstration together with private industry partners on the PWRI and JARI Test Tracks in Tsukuba, Japan. On the PWRI test course, the following systems were highlighted:

- Forward collision warning
- Lane departure warning
- Side impact/collision warning (right turns, cross-vehicular traffic, pedestrian traffic)
- Roadway condition warning (curvature, surface)

The technologies behind these systems are primarily infrastructure-based with:

- Sensors
- Infrastructure-centered data processing facilities
- Two-way communication beacons
- Lane markers[3]

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[3] PATH participated in Smart Cruise 21 Demo 2000 demonstrating three scenarios with a vehicle that provided automatic steering control, driver lane guidance, and lane departure warning on the PWRI Test Track in Tsukuba City, Japan. Complete details are available in "PDF" format in the complete research report located at:

On the JARI test course, Advanced Safety Vehicle systems were showcased including:

- Forward collision warning
- Forward collision avoidance
- Adaptive cruise control with brake control
- Heads-up display
- Side collision warning
- Lane departure warning
- Roadway condition warning
- Drowsy driver warning
- Rear vehicle proximity monitoring

5.0   CONCLUSIONS AND NEXT STEPS

The work reported here was a direct continuation of the prior research in PATH Task Order 366, continuing to expand our understanding of the issues involved with time-staging the deployment of advanced vehicle control and safety systems (AVCSS) to help lead toward future automated highway systems. The time-staging challenge has long been identified as one of the most significant impediments to deployment, particularly because of the "chicken and egg" problem associated with vehicle and infrastructure technology implementation.

The detailed review of the international status of AVCSS development, in collaboration with the European Commission's STARDUST project, provides a comprehensive picture of the status of these technologies not only in the U.S., but also in Japan and Europe (and the European review, provided in Appendix A, was produced by the European partners in the project, in exchange for our review for them of the situation in the U.S. and Japan). All three major industrialized regions of the world are struggling with similar "chicken and egg" deployment challenges, but the specific features are different, based on the differences in the political and institutional structures in the different countries.

The basic principles of earliest deployments of the more advanced technologies in transit buses and heavy trucks appear to apply similarly across the countries because of similar economic circumstances and expected benefits. The deployments must in each case be based on the ability of the technologies to solve significant transportation problems, because the technology-push model of a "solution looking for a problem" is not generally viable. The transportation industries and agencies whose problems could be solved by AVCSS technologies are not necessarily aware of these opportunities, and need to be educated more effectively about the possibilities than they have been heretofore. The general categories of transportation benefits are defined here, but detailed quantification of those benefits will have to depend on case studies addressing site-specific transportation problems and the ways in which AVCSS technologies can help in solving them.

Although the bus and truck opportunities are likely to develop earliest, the largest potential benefits are still likely when the technologies are applied to the much larger population of passenger cars. The first stage in passenger car implementations that could provide benefits beyond the comfort and convenience of adaptive cruise control (ACC) is likely to be

cooperative ACC (CACC). A detailed modeling approach for predicting the highway capacity benefits of CACC is described here, but the benefits have only been predicted for a single-lane example because of the complexities of modeling lane changing behavior in multi-lane driving environments. The lane capacity benefits of CACC are potentially so substantial that this requires further research, specifically to narrow down the remaining uncertainties about the underlying assumptions in the CACC analysis. The key issue to be addressed there is determining how willing drivers will be to operate their cars closer together when they have high-performance CACC available (based on tighter control of gap variations between vehicles). This will be tested with a representative selection of drivers from the general population in a new project that has been proposed as the next stage in this sequence of research. The results of those human factors experiments with naïve drivers driving the CACC vehicles, will provide vital data to calibrate the model of car-following behavior that determines the extent of the lane capacity increase that can actually be achieved.

LITERATURE REVIEW OF ADAS/AVG (AVCSS) FOR EUROPE

Submitted to:
STARDUST Consortium Team

Submitted by:
Michel Parent
INRIA, France

Date:
July 4, 2001

Table of Contents

1 INSTITUTIONAL CONTEXT: OVERVIEW OF GOVERNMENT ROLES IN EUROPE

Research on transport in Europe is carried out at basically three levels: at the industrial level without any government support (sometimes with the involvement of public or private research organisations under contract from the industry), at the national level through contracts or research grants, usually involving several partners and at the European level through research contracts awarded by the European Commission under different procedures. There exist also another light procedure to do research between two or more European partners with public funding: the Eureka procedure.

We will not talk about the way the research is carried out at the pure industrial level since it is similar to any other country and there is no special incentive involved. We will simply concentrate on the government roles at the national level and at the European level.

At the national level, there are as many national policies as there are countries in Europe and each country defines its own way to encourage (or not) research in the field of transportation. Here we will mention some of the countries with the most active research policies in road transport.

1.1 The Netherlands

Although a small country, the Netherlands has always been a pioneer in transportation research because of its key position in Europe as a major entry and exit point. Indeed, Rotterdam is one of the second largest container terminal in the world and hence a major gate for freight transport in Europe. Holland is also famous for its very congested highways due to this large transportation demand and also due to the high population density.

Transportation research is sponsored by the government mainly through the famous Rijkswaterstaat (RWS), which is a Directorate of the Ministry of Transport and Public Works in the Netherlands. The RWS is responsible for land and water based transport infrastructure, planning, management and maintenance. RWS operates through a number of national organisations and through regional directorates. The Regional Directorates cover the areas of the provincial administrations. They are the operators of the road and traffic management systems.

Rijkswaterstaat is responsible for the traffic management and control functions on the strategic road network in the Netherlands. This consists of approximately 2000 kilometres of motorway and some 4000 kilometres of road of non motorway standard. RWS also supports cities in the development and implementation of their traffic management schemes.

The RWS carries its own research through its research centre, the Transport Research Centre (RWS-AVV http://avvisn0.rws-avv.nl/cgi-bin/wdbcgiw/avv/AVV.home) but also through grants to private research organisations such as TNO and universities and also to industry. It was RWS-AVV which organised the first European demonstration of advanced vehicles systems in June 1998.

The RWS is now preparing a very large project on Fully Automated Vehicles (FAV) research due to start next year. The estimated budget for this programme should be in the order of 150 M€. The focus would be on people and good transportation in urban environments.

1.2 France
France has one of the largest road networks comprising both rural roads (500,000 km) and major freeways (about 4,000 km often with toll). However, it also has one of the largest accident rates in Europe with close to 8,000 deaths per year. Although there has been significant improvements in road safety in the last thirty years, progresses seem to have come to a limit.

Transportation research in France is sponsored by the government essentially through several ministries: Ministry of Research, Ministry of Transport, Ministry of Industry and Ministry of the City. These ministries have basically two ways to encourage research in this field: through the annual or pluriannual funding of public research organisations and through contracts with public and private organisations.

There are four major national research organisations (plus the universities) which receive yearly funding from the government on the subject of driving assistance:

INRETS, the national research laboratory on transport and safety (www.inrets.fr),
LCPC, the national research laboratory on road infrastructures (www.lcpc.fr),
INRIA, the national research laboratory on informatics and automation (www.inria.fr),
CNRS, the national scientific research organisation (www.cnrs.fr).

Each of these public research organisations has discussed with their funding bodies, pluriannual programmes where research on ITS in general and driving assistance in particular are explicitly requested.

Recently INRETS and LCPC have opened a joint research laboratory on driving assistance: the LIVIC (http://www.inrets.fr:80/ur/livic/livic.e.html) based in Versailles to study more precisely the interactions between the vehicle, the infrastructure and the driver. The LIVIC has access to test tracks on its grounds.

The first three research laboratories have also joined forces with three top engineering schools (Ecole Nationale Supérieure des Mines de Paris, Ecole Nationale des Ponts et Chaussées and Ecole Nationale Supérieure des Télécommunications) to form an informal research consortium on driving assistance called "La Route Automatisée" (www.lara.prd.fr). This consortium has been awarded specific contracts to work on the evaluation of scenarios for the Automated Highway but its work also encompasses driving assistance.

Research under contracts on the field of transportation has been organised in France since many years under global programmes of four year duration like for European programmes. The last one (1998-2002) was called PREDIT (http://www.predit.prd.fr/) and has just been extended with another similar 4 year programme called PREDIT II (2002-2006). Periodic calls are issued every year on specific areas. In these programmes, a large part is focused on "la Route Intelligente" or road ITS. These programmes are under a global management of the four interested ministries but the contracts are generally awarded by only one of them depending on the subject and on the partners. Cooperative work between industry and public research is always encouraged in these contracts.

Under the PREDIT, a large programme called ARCOS (Action de Recherche pour la Conduite Sécurisée) is being launched under the leadership of INRETS. This programme which should cost more than 12 M€ and involve about 50 French partners is focused on new technologies and studies to improve road safety. The goal is to reduce accidents by 30% by 2005.

1.3 Europe
European research policy is defined every 4 years through a debate carried at the European parliament. The programme is elaborated by the different Directorates General (DG) with a budget and both are discussed and voted in the parliament. The four year programmes are called "Frame Work Programmes" (FWP) and are constituted by a number of calls for propositions, each with its own budget. The propositions are made by consortia of at least two members of different countries of the European Union (or some "associated countries") and possibly from some other "invited countries". In these last case, funding comes from these countries and not from the EU. The average consortia size is around 6 partners. Funding by the EU is between 30% and 50% of the total cost.

The last FWP (the 5th) was launched in 1998 and the next one is now in discussion to be approved by the end of 2001.

The current FWP was divided into a number of sub-programmes, each with a number of "Key Actions". Each key action has its own budget and its own calls. Transport technologies are of interest in several Key Actions which are described bellow (excerpts from the calls) to be found in three programmes.

1.3.1 PROGRAMME IST (Information Society Technologies)

The Context
The convergence of Information Society technologies and markets is leading to new products and services that are increasingly transforming our lives. Examples may be seen in the emergence of appliances for accessing both interactive and broadcasting services and in the development of intelligent home and office environments that provide users with easier and any-where access to services. The impact of IST on every-day's activity is also raising people's expectations for a better quality of life. As technology is becoming part of our normal surroundings, new tools for content creation and diffusion provide individuals with powerful means to express ideas and develop their creativity for professional use or for leisure.

The rapid deployment of e-commerce and the expansion of mobile and global access to services are driving enterprises to continuously modify their business models. They can build on advances in technology such as component-based development and platform independence, better to master and integrate their value chains. While this provides greater flexibility and allows them to react instantly to changing market needs, it also induces considerable shifts in working modes and structures.
Underlying these advances is the development of a multipurpose computing, broadcasting and communications infrastructure. In the last two years, Internet and mobile systems have been driving development in the field. The move towards closer integration between internet-based, and fixed and mobile technologies as well as progress in middle-ware and multi-tier architectures are paving the way for the realisation of a global distributed and shared infrastructure. RTD is leading to improved authentication techniques and more dependable systems. Ensuring higher

confidence in the technology and the related infrastructure is an essential condition for participation of citizens in the Information Society.

Key Action I - SYSTEMS AND SERVICES FOR THE CITIZEN

Objectives
"The aim of this work is to foster the creation of the next generation of user-friendly, dependable, cost-effective and interoperable general-interest services, meeting user demands for flexible access, for everybody, from anywhere, at any time. Work, including the associated education and training, encompasses RTD addressing the whole of the Key Action, as well as specific RTD in the following fields: health; special needs (including ageing and disability); administrations, environment; transport and tourism. Certain of the ubiquitous issues addressed throughout the whole of this programme will be taken up further in order to pay due consideration to the needs and expectations of the typical users in this Key Action, in particular the usability and acceptability of new services, including the security and privacy of information and the socio-economic and ethical aspects."

Transport and Tourism
For RTD Action Lines work will be expected to address industrial consensus on common specifications as well as establishing or enhancing standards where appropriate. Furthermore, preparatory activities for the uptake of successful results by the relevant tourism authorities should be addressed.

IST 2000 –1.5.1   Intelligent transport infrastructures
Objectives: To improve mobility management in support of sustainable economic growth in Europe and for improving the quality of life of citizens.

Focus:
〈 Advanced IST surveillance and control systems focused on safety in road tunnels and railways.
〈 Intelligent integrated urban and interurban traffic management systems, including co-ordinated motorway control, management of large-scale events and crises, management of over-saturated networks and network disruptions, including advanced modelling and simulation.
〈 Advanced IST systems for supporting logistics and co-operative resources management for the whole transport chain.
This work will support integrated sustainable passenger and freight transport locally and across Europe.

IST 2000 - I.5.2   Intelligent vehicle systems
Objectives: To improve safety, security, comfort and efficiency in all modes of transport. This is achievable through the emergence of ambient intelligence within the vehicle for the direct benefit of all citizens.

Focus:

〈 Advanced driver/pilot assistance systems for vision and alertness enhancement, safety of manoeuvring, automated driving, compliance with regulations, providing and reacting to emergency, traffic and weather information.

◇ Advanced systems for providing teleservices in areas such as maintenance, dependability, remote diagnostics and vehicle performance including environmental aspects, info-mobility and infotainment.

For the above two application domains (safety and operations), work will address in-vehicle platforms, interfaces to the user and to services that will include vehicle-to-vehicle and vehicle-to-infrastructure communication.

Additionally, system test and evaluation methodologies will be considered in order to ensure dependable and optimal use of components and the development of industrial consensus on common specifications and in-vehicle platforms.

IST 2000 - I.5.3   Best practice and demonstration actions in electronic fee collection

Objectives: To promote the uptake of standardised solutions for multifunctional electronic fee collection and payment systems in the domain of transport in the regions of Member and Associated States.

Focus:

To develop, demonstrate and promote awareness of multifunctional electronic fee collection and payment systems' equipment and installations (based on Dedicated Short-Range Communications – DSRC – standards and/or mobile communications and satellite location technologies). Work should support demand management and should include collection of road user charges, fare payment, parking payment and access control. It should enable the integration of electronic payment across different transport applications. This activity will, whenever applicable, interact with the relevant policy-related research and demonstration activities outlined in the Growth Programme in the Key Action on Sustainable Mobility and Intermodality.

Three domains will be covered:

◇ Best practice awareness actions aimed at promoting exchange of best practice, co-ordination and interoperable solutions for the use of multifunctional electronic fee collection and payment systems across Europe.

◇ Demonstrations providing a test-bed for secure, on-line access technologies that ensure privacy. These demonstrations should support local, regional and national authorities in the stimulation of the take-up of multifunctional electronic fee collection and payment systems, including the associated dissemination.

◇ Integration and demonstration of multifunctional electronic fee collection and payment system equipment and installations across different transport and other applications, including contact-less operation in public transport vehicles and fixed infrastructure.

1.3.2 PROGRAMME EESD (Energy, Environment and Sustainable Development)

Key Action 4: City Of Tomorrow And Cultural Heritage

About three-quarters of the EU population lives in urban areas. Over 30% of all transport kilometres are made in towns. Energy consumption of transport in cities is increasing rapidly, with private cars and commercial vehicles being responsible for 98% of energy consumption in urban transport. Urban traffic is responsible for more than 10% of all CO_2 emissions in the EU.

The danger of unsustainable traffic growth, worsening living conditions as well as new political commitments such as the Kyoto protocol, emphasise the urgent need to reverse these trends. Radical change is required, based upon a mixture of technology and policy based measures. Research into the effectiveness of individual measures has a role to play, as has development

and demonstration. However, there is also a critical role for demonstration and assessment projects that integrate a package of measures and are of a sufficiently large size to make a visible impact.

The objective of this Targeted Action is to assess the impacts on energy consumption, traffic conditions and pollution in cities of radical new sustainable urban transport policy strategies, supported by innovative measures, technologies and infrastructures. These strategies should particularly aim at achieving a shift in modal choice of people, who have the option of car use, towards alternatives.

The proposals should combine energy-efficient, cost-effective and clean public and/or private vehicle fleets, based upon minimum the Euro-4 standard, and the necessary fixed infrastructure (e.g. fuelling), with a wider package of measures in order to cover both the transport demand and supply side. This package should include innovative demand management strategies based upon access restriction and integrated pricing; stimulation of collective passenger transport and new concepts for goods distribution; new forms of vehicle ownership and use; innovative 'soft' measures for managing mobility demand and awareness raising; and transport management systems and related information services.

Objectives
Across Europe there is a common challenge to improve the quality of life in urban communities and the associated urban regions, and to ensure the competitiveness of European cities while promoting sustainable development assessed in economic, architecture, environmental, social and cultural terms. Cities differ in terms of culture, environmental conditions, size, economic structure, social composition and demography. Despite these differences cities in all European regions face common challenges such as those relating to air quality, noise, traffic congestion, waste, economic competitiveness, employment, security, and maintaining their deteriorating infrastructure and built environment while reducing social exclusion and promoting sustainable development and enhancement of cultural identity.

This key action will pursue a mix of socio-economic, environmental and technological approaches including the development, integration, and demonstration of technologies, tools and methodologies to improve forecasting, monitoring and assessment and establishing best practices. Emphasis will be given to approaches increasing citizen and stakeholder participation in urban decision making and helping ensure the availability of reliable, efficient and affordable services for all urban citizens, including those with special needs.
Comparative assessment and cost effective implementation of strategies for sustainable transport systems in an urban environment. The objective is to radically reduce urban pollution and congestion, while ensuring accessibility and mobility, through strategic approaches towards land use patterns favourable to the development of alternatives to the private car and towards the introduction of new urban transport technologies compatible with the overall transport system.
Anticipated deliverables: policy incentives, essential planning tools, assessment methodologies and best practices aimed at reducing individual vehicle movements and encouraging greater use of collective and other sustainable transport forms; assessment and demonstration of how new and integrated urban transport technologies can improve mobility, accessibility and the quality of life

RTD Priorities

Strategic approaches and methodologies in urban planning towards sustainable urban transport. The target is to develop planning tools, assessment methodologies and best practices aimed at managing future transport demand through integrated land-use planning and transport planning, reducing individual motorised vehicle movements and encouraging greater use of collective and other sustainable transport modes. To implement optimised urban planning in a sustainable way requires indicators, scenarios and models to describe and optimise urban land-use and transport patterns; analysis of the institutional, legal and financial barriers to optimised planning; development and evaluation of urban infrastructure promoting the use of non-motorised modes.

Comparative assessment and demonstration of new transport technologies and related infrastructure. Improved concept simulation and evaluation of urban transport/transit means in a specific urban context: vehicle/transit system modelling, simulation, and cost benefit analysis and assessment, life-cycle analysis, niche management supported by prototype testing, demonstration, and validation; real-scale demonstration and assessment of urban transport concepts with provision of user-friendly new vehicle concepts for personal, or freight transport; improved vehicle / urban infrastructure compatibility.

1.3.3 GROWTH PROGRAMME

KEY ACTION 2: SUSTAINABLE MOBILITY AND INTERMODALITY

Compared to the other key actions of this programme, this key action is largely policy-driven and therefore justifies a more detailed definition of the objectives and a more direct involvement of policy-makers from Member States. The key challenge is how to reconcile the increased demand for transport on the one hand and the need to reduce its impact on the physical, social and human environment on the other hand, and how to reduce the transport intensity of economic growth. This key action offers the opportunity to involve all stakeholders in facing this challenge and in enhancing innovation in the transport sector by fostering the use of new technologies, developing new services and providing new concepts and policies. The key action bases itself on an integrated systems approach to transport. As the road, rail, waterborne and air transport modes are at different stages of their development, their optimisation from a modal perspective will continue to be necessary. However, a major focus will be to enhance the integration between the different modes of transport in respect to infrastructure, operations, services, procedures and regulations. In other words, to enhance intermodality in order to enable a better use of existing capacities.

This key action will help the Union to further develop and implement the objectives of the Common Transport Policy and those of national transport policies:

- promoting transport **sustainability** from an economic, social and environmental point of view;

- enhancing the **efficiency and quality** of transport systems and services;

- improving **safety and security** and optimising the **human role and performance.**

It will also support other Community policies in such fields as energy, industry, environment, employment, cohesion and the fight against fraud, in co-ordination with other key actions as outlined under section E of this work programme.

For *sustainability*, the aim is to promote a long-term balance between the growing demand for mobility on the one hand and the necessity to respect environmental, safety social and economic constraints on the other. Some parameters to guide the key action's activities should be to enable the transport sector to contribute to the realisation of ambitious standards for air quality and noise in a cost-effective way, and to reduce the growth of transport CO_2 emissions as well as to enhance the attractiveness and accessibility of more sustainable transport modes such as rail, inland waterways and short sea shipping and to increase the use of public transport.

For *enhanced efficiency and quality* the aim is to improve the overall cost-effectiveness and functioning of transport operations and infrastructure. Particular attention will be paid to how best integrate the respective strengths of all modes of transport in order to provide door-to-door services for both passengers and freight. Some parameters should be focused for example to significantly reduce congestion in the networks by the year 2010; to reduce the average viability threshold for intermodal freight journeys in the European Union from ca 500 km to 200 km by the year 2010; to support Community policy in the field of transport charging across Europe and to integrate information technologies and second generation satellite navigation and positioning systems in the transport sector.

For *safety, security and human factors* the aim is to ensure a high level of safety and user-friendliness at an affordable cost for the individual user as well as for society. Parameters to be taken into account include the development and promotion of the use of new technological and behaviour-orientated tools to reduce the number, severity and impact of accidents, both in terms of safety and pollution prevention. The parameters should also significantly reduce the total number of fatal and other severe accidents, in particular in road transport and improve travellers' perception of security and to reduce loss or damage of goods.

RESEARCH OBJECTIVES
The key action's three RTD objectives, which contribute to achieving the policy goal of sustainable mobility, reflect the three main components of a modern integrated transport system:

(i)   a regulatory and accountable framework reflecting socio-economic objectives;

(ii) an interoperable infrastructure which allows the operation of attractive, environmentally-friendly and efficient transport means;

(iii)   modal and intermodal systems for managing operations and providing services.

Socio-economic scenarios	Infrastructures and interfaces with transport means	Transport management
2.1.1. Quantitative tools for decision-making	2.2.1. Infrastructure development & maintenance	2.3.1. Traffic management systems
2.1.2. Driving forces in transport	2.2.2. Environment	2.3.2. Transport and mobility services
2.1.3. Policies for sustainable mobility	2.2.3. Safety	2.3.3. Second generation GNSS
	2.2.4. Security	
	2.2.5. Human factors	

"2.1 Socio-economic scenarios for mobility of people and goods"
The aim is to develop strategies and tools for managing the impact of economic, social, political, demographic and technological developments on mobility demand and transport policies. Research will deliver the building blocks for a European strategic decision support and information system in the field of transport for policy-makers, authorities, industry and operators. The three major building blocks are quantitative tools, knowledge of today's and tomorrow's driving forces in transport and effective policies. These basic decision-support tools will provide the keys to further refine and operationalise the concept of sustainable mobility to further develop integrated transport systems in the specific European context.

"2.1.1: Quantitative tools for decision-making"

In order to anticipate, orient and respond to mobility needs, transport models have to be refined and developed to explain and predict the user's travel and transport decisions in a reliable way. They will also have to allow the evaluation of the impact of different transport policies and developments in terms of economic effects, employment, environment, safety and cohesion so that comprehensive assessments can be made. In particular, models and other evaluation tools will be designed that facilitate priority setting in the further development of the Trans-European Networks and the elaboration of other elements of the Common Transport Policy.

The **strategic information and evaluation systems** to be developed will support higher-level customised applications, guide decision-makers in planning the transport system and operations, and enable the assessment of projects and initiatives. The development of these systems requires new methodologies for data collection for specific transport domains where information is not available for use at European and global level such as mobility trends, origin-destination matrices, accidents, internal and external transport costs, emissions, both for passenger and for freight transport. It requires also setting up of coherent market observation tools and benchmarking methodologies, integration of assessment tools and models responding to policy-related queries, as well as improved models and evaluation methodologies.

"2.1.2: Driving forces in transport"

Present decisions and investments in transport determine the shape of Europe's future transport system. An early identification of future challenges and bottlenecks should enable decision-makers to better cater for current and future mobility needs. This requires the quantitative tools developed in sub-task 2.1.1. to be complemented with research into driving forces in transport that cannot be adequately addressed by quantitative forecasting tools.

Building integrated and sustainable transport systems in Europe to cater for current and future mobility needs will require research to produce structured and comprehensive frameworks which identify the political, social, economic, cultural, demographic and technological factors (including their impact assessment) which are likely to shape mobility and the transport business, including supply chain management, today and in the future. It will also require the preparation of long term reference scenarios, which portray sustainable mobility concepts for the future, defining their operational, technical and regulatory requirements and ways to get there. Prospects on how European integration, enlargement to the East, regional differences and subsidiarity are likely to determine transport in the Union need to be addressed as well as an identification of the most effective strategies to develop integrated and sustainable transport systems in this particular European context, responding at the same time to the challenges and opportunities raised by a continued globalisation of economic activities.

"2.1.3: Policies for Sustainable Mobility"

The third building block consists of efficient policies for sustainable mobility, taking into account the tools developed under the preceding objectives. Research on policy evaluation, implementation, acceptance and their further development will enhance the decision-making process and the execution of policies at pan-European, EU, national and regional levels.

An improved **development and implementation of policies** require research on strategies for dealing with possibly conflicting policy objectives and their implementation in terms of transport demand, environmental and safety impact, social, economic and regional cohesion, land-use planning; policy evaluation that combines economic analysis, environmental impact and safety assessment; regulatory enforcement techniques and methods as well as tools to measure the impact of non-enforcement of regulations; optimal legal, institutional and organisational structures for the transport sector as well as evaluation of needs and opportunities for public intervention and public-private partnerships. Finally research will also have to address optimal pricing policies, their relationship with infrastructure investment and operational strategies, their impact on society and ways to increase their public acceptability.

"2.2 Infrastructures and their interfaces with transport means and systems"
The goal is to enhance interconnectivity and interoperability in order to promote efficiency in the transport system through further strengthening the modes and enhancing their integration in terms of infrastructure, transfer points, transport means (vehicles, vessels…), equipment, operations, services and the regulatory framework. Strengthening the modes also implies improving safety and security as well as their environmental-friendliness.

"2.2.1: Infrastructure development and maintenance"

The operation of seamless intermodal door-to-door transport chains across Europe requires research to enable the cost-effective development and maintenance of infrastructures and nodal areas as well as to identify and realise promising alternative transport concepts.

The further **development, interconnection and interoperability of transport networks, in particular the Trans-European Transport Networks (TENs)** require research to address specifications for technical and administrative interoperability within and across modes; the identification of Trans-European and network effects of TENs and strategies to maximise their beneficial impacts; methodologies and best practices for improving the integration between

local, regional and Trans-European and Pan-European networks, particularly in cross-border situations including new concepts to optimise the intermodal use of cargo units.

The optimisation of **nodal areas and terminals**, key elements of seamless intermodal networks, requires planning and design tools to better integrate ports, airports and inland terminals in the network as well as good practice guidance in planning, financing and operating accessible passenger interchanges.

For an improved and cost-efficient **infrastructure maintenance,** research will provide tools for infrastructure management and maintenance such as methodologies for life cycle cost assessment and business process re-engineering, infrastructure materials and tools to optimise the interaction between the infrastructure and the vehicle and strategies for cost-effective and reliable maintenance of transport means as well as condition-based and reliability-centred systems for infrastructure management for all types of infrastructure and all safety-critical components.

In order to develop innovative and cost-effective **alternative transport concepts** and to assess their potential impact, research is required on two areas. First, the needs and opportunities for new transport means and systems over the next 10 to 30 years, such as the innovative use of pipelines, floating tunnels, automated underground distribution systems, large capacity transport means, including investigations as to how current means could fulfil future requirements and how innovative technologies can be integrated. Second, the safe, efficient and environmentally-friendly integration of new means of transport, e.g. high-speed vessels, into existing transport operations.

These activities are closely co-ordinated with the Generic Activity "Materials and their technologies for production and transformation" as well as with KA1 "Products, processes and organisation", in particular regarding **tunnels**.

"2.2.2: Environment"

The aim is (1) to develop European harmonised methodologies to assess and monitor the effects of transport infrastructure and operations on the environment, and (2) to evaluate technologies, develop concepts and identify regulatory requirements to mitigate air pollution and noise from transport.

Decisions on environmental measures in transport require an adequate **assessment of the environmental impact of transport**. Therefore, research will have to address among other things measurement of noise and emissions, accidental and operational pollution, including regulated as well as non-regulated pollutants such as particulate matters and base metals as well as refinement of methodologies and procedures to evaluate the environmental impact of transport infrastructure master plans, international corridors and projects, as well as transport operations and alternative logistics chains and to integrate these into the broader socio-economic assessment (including Strategic and Environmental Assessments).

In order to **mitigate the environmental impact of transport**, research will have to address four areas. First, strategies for the abatement of noise and pollutant emissions in cities, at ports and airports and in the vicinity of large transport infrastructures. Second, new technical and regulatory requirements for enhancing the environmental compatibility of vehicle, train, aircraft and vessel operations. Third, specifications of environmentally compatible infrastructures, including solutions to lower their visual intrusion in the environment and lastly organisational

and policy frameworks for the introduction and use of environmentally friendly transport means and systems.

"2.2.3: Safety"

The aim is to develop and implement systematic approaches to safety in all modes of transport within a cost-effectiveness perspective. Research should provide the foundation for harmonised pan-European safety regulations.

The development of methodologies for a **systematic safety approach and risk analysis** in transport requires first of all common methodologies and tools for hazard and risk analysis, for the establishment of safety requirement targets and related safety control procedures and for the elaboration of safety assurance and management procedures as well as systematic approaches to emergency situations, including passenger survivability and evacuation from transport means and all kinds of infrastructure and for search and rescue. Furthermore, methodologies for cost-effectiveness assessment of transport safety measures and vehicle design improvements and methods and tools for implementation and enforcement of safety regulations and strategies will need to be developed, including also for the transport of dangerous goods. Finally, rules and procedures for the integration and use of safety enhancing navigational, management and information systems and automated solutions as well as assessment of the role of the human element and how to ensure a positive impact of telematics on safety and the increased use of communication devices needs to be addressed, and should also take into account the results of the "User-friendly information society" (IST) programme.

Research will also address **specific safety issues,** such as the feasibility of transferring design methodologies and technologies to increase passenger survivability from the automobile area to aircraft, ships and railways, and vice-versa; safety risks of and solutions to the existence of different traffic signs and regulations across Europe; performance assessment of drivers' and crew behaviour and physical state in relation to illness, fatigue and the use or abuse of alcohol, various types of drugs and medicines as well as confidential reporting schemes for hazardous incidents.

"2.2.4: Security"

Research should deliver strategies and tools to guarantee higher levels of security in transport. Improving **security** for passengers and cargo will require research, in co-operation with the IST programme, in three areas. First, reconciliation systems for luggage and goods in ships, aircraft and terminals. Second, security aspects of public transport, including automatic detection of security problems and incidents and security-enhancing conception and operation of facilities and transport means (including piracy prevention). Finally, harmonised security procedures for intermodal transport operations and organisation of measures on door-to-door transport chains as well as early warning and cargo security systems and measures.

"2.2.5: Human factors"

The aim is (1) to improve the human role and performance in transport operations, (2) to assess the future training needs and opportunities for jobs, while at the same time, (3) increasing the levels of comfort in and accessibility to transport means.

Improving the **human role and performance** in transport necessitates research to provide systematic approaches to the many factors which affect the interaction between human beings and automated systems in transport, such as the assessment of driver assistance systems and

the development and acceptance of new procedures and technologies as well as the assessment of health effects of transport, including of transport at high speed and high altitude.

In the field of **training and education**, research will address the following issues: training tools and techniques for crisis management by staff in aircraft, vessels, vehicles and passenger interchanges; harmonised procedures to implement international regulations related to training and education; training and assistance systems for drivers and crew; new jobs, strategies for qualification and career development related to structural changes in rail, public transport and maritime transport, including ports as well as European educational and (re-) training needs for transport professionals, including the use of simulators.

Increased levels of **comfort and accessibility** in transport will be achieved through research on strategies to improve access to transport and identification of the wider socio-economic cross-sector benefits of accessible transport and new designs for transport means and terminals to be accessible to all people.

"2.3 Modal and intermodal transport management systems"

The aim is to develop and facilitate the deployment of high-performance systems for managing traffic and transport services both on a modal basis for air, waterborne, rail, road and urban transport, and for intermodal transport. The development of second generation satellite navigation and positioning systems is thereby seen as an important contributing tool. These activities will be undertaken in liaison with the programme for a user-friendly information society and will include the use of related information systems, their integration into the transport system and the validation of the resulting integrated systems, including institutional solutions for their deployment.

"2.3.1: Traffic management systems"

A more efficient, safe and environmentally friendly use of available infrastructures requires an appropriate management of traffic flows. The three main aims in this respect are: (1) to contribute to the development, integration and validation of advanced traffic management systems, including the exchange between and the use of information systems; (2) to establish a coherent, integrated transport management systems architecture across the transport chain; and (3) to fine tune demand management tools and policies and facilitate their deployment.

In order to improve **traffic flow management**, developments will be centred on the following four issues, building on the results obtained within FP4. First, assessment of new European concepts and functions of vessel traffic management and information services (VTMIS) and river information services (RIS) for optimised waterborne transport management services including safe ship operations, contingency planning and increased traffic efficiency; improvement of navigational control and shore-based advice and pilotage; specific requirements for high speed craft. Second, extension of the European Rail Traffic Management System (ERTMS) towards the traffic management layers, including capacity analysis and allocation, building on the current signalling (ERTM/ETCS) and telecommunications (GSM-R) developments, including the use of an associated information infrastructure to support transport management activities and customer services. Third, in line with the conclusion of the High Level Group on the reform of Air Traffic Management ("Single Sky"), to improve the operation of air traffic control systems, inter alia by validation in a structural way of the benefits and feasibility of the implementation of a European Air Traffic Management System (EATMS system), through integration and operational verification. Finally, transport policy assessment of automated guided vehicles and dynamic road traffic management systems,

including incident management, covering operational procedures for data collection, processing, modelling and information provision to road users and road operators as well as the development of solutions to suit agreed levels of interoperability between road-based information and management systems across the EU.

Research also has to develop the basis for **integrated transport management architecture** across the transport chain, notably through the establishment of procedures for the exchange across modes and sectors of transport information and documents as well as of tools and methods to optimise the management of intermodal transport chains and the interconnection between nodal points, including their interfaces with incoming and outgoing traffic and integrating supporting information and communication systems. Finally, safe and efficient management of nodal points such as airports, ports and freight terminals will have to be addressed.

Demand management tools such as pricing policies and their practical implementation both across modes as well as in modal situations require research and development on design of transport pricing schemes, including distance-based road pricing systems and mobility management schemes at site and area level and for tourism related mobility, including the development of policy scenarios promoting mobility management.

"2.3.2: Transport and mobility services"

Increasing the transport system's efficiency and sustainability, and promoting a modal shift require improved and innovative transport and mobility services and strategies. RTD should help to: (1) lower the break-even distance of intermodal freight transport and enhance the quality of intermodal freight services, (2) improve the quality and use of collective passenger transport, non-motorised modes and taxis in local and regional passenger transport; and (3) enable a better use of existing infrastructure and capacities through common freight and passenger services.

In order to enhance the quality of intermodal **door-to-door freight and logistics** services in all modes, both in urban and rural areas, research activities will cover four areas. First, new strategies for intermodal transport with particular emphasis on innovative concepts for short and medium distance services for non-standardised cargoes and small consignments. Second, new organisational solutions to improve the service quality of goods-distribution within urban and rural areas, and between these areas and freight centres. Third, the users requirements and the operational deployment of open and accessible information systems, building inter alia on electronic business, that will offer reliable real time information and other value added services to all actors in the transport chain with the aim of reducing their costs and to enable co-operative freight management. Finally, strategic tools to optimise the organisation of transport in the framework of logistic processes.

An improved **integration of individual modes** in the transport chain requires different organisational and technical solutions. Research will therefore address the following areas : the potential for rail/air freight services with innovative freight centres at airports; innovative concepts for door-to-door services integrating short sea shipping and inland navigation, in particular the role of waterborne transport management services in achieving efficient intermodal freight operations; emerging opportunities for new operational railway concepts and services, including the development of the European Rail Freight Freeways as part of door-to-door

transport services and finally, intelligent intermodal transport equipment, including rail/road, to improve transport chain efficiency.

Improved **passenger transport systems and services** will be developed, validated and demonstrated in order to improve the quality and use of collective transport, non-motorised modes and taxis in local and regional transport. Research will address the following areas. First, intermediate mass transit systems to fill the gap between bus, tram and other public transport systems. Second, innovative customer-tailored services based upon specific traveller groups´ market needs such as mobility-impaired people, night-travellers, students and business-travellers. Third, use of non-motorised transport modes and taxis, especially in combination with public transport and finally, organisational and other requirements for door-to-door passenger services using inter alia integrated travel information, reservation, payment and ticketing.

In order to enhance the attractiveness of environmentally friendly transport modes at local, regional, national and international level and to promote behavioural change, through **common concepts for freight and passenger services**, research activities will cover good practice in planning and designing transport networks and services, particularly with regard to innovative financial and organisational partnerships for rural areas, city centres and low-density residential areas. It will also address strategies and tools for behavioural change in freight and passenger transport through awareness and marketing campaigns as well as standard European markets segmentation and a set of indicators for local transport and strategies for the promotion of its use for benchmarking and decision making.

"2.3.3: Second Generation Satellite Navigation and Positioning Systems"
The aim is to contribute to the development and implementation of a European strategy regarding the second-generation satellite navigation and positioning systems (GNSS). Whereas in the space and ground control segments the focus of the work will evolve from policy decisions regarding international co-operation, in the application segment, research will aim at fostering the utilisation of satellite navigation and positioning systems across the value-chain of the transport sector. With regard to **second-generation satellite navigation and positioning systems** (Galileo), research and development will cover the following three areas in conjunction with the IST programme. First, the development of a technological and operational capability, enabling Europe to play a decisive role in future international, world-wide space co-operation agreements. In this context, appropriate co-ordination mechanisms will be implemented in order to ensure the maximum synergies with the work carried out by ESA and, where appropriate, potential users. Second, the development and implementation of a strategy for fostering the penetration of satellite-based navigation and positioning systems across the transport sector, as a performance enhancement in safety-critical applications, as a more cost-effective and operationally-efficient replacement of existing operational infrastructure, and as a means to support the creation of new value-added services, particularly in an intermodal context. Emphasis will be given to field demonstrations as well as to the consideration of the underpinning economic, institutional, legal and regulatory aspects. Third, the analysis of user requirements, opportunities and constraints linked to the specifics of the various transport modes and infrastructures.

STRATEGY

In defining the **strategy and priorities** for the December 2000 and the June 2001 calls for proposals, attention has been paid to the policy priorities established by the Commission, to

the relevant results from FP4 (Fourth Framework Programme) projects and to the first steps of FP5 projects. Particular importance has been given to the integration, validation, demonstration and assessment of previous project results to facilitate transport policy decision-making and implementation at European, national and local levels.

The new approach for the implementation of all key action activities will focus on two main elements:

- **concentration** of a substantial fraction of the key action activities around a core set of Targeted Actions which are designed to facilitate the emergence of solutions with a measurable impact, high profile and direct relevance to EU policy objectives. Targeted Actions integrate multidisciplinary and multisectoral activities involving, wherever possible, private-public sector partnerships and end-users from the business, industrial and policy-making sectors;

- identification of a **limited number of priorities** of strategic importance to the EU, which are to be addressed by proposals related to the topics of the Work Programme.

The Commission wishes to give encouragement to proposals of outstanding quality; of appropriate size; which are able to contribute to achieving critical mass in priority topics; and which have the highest possible impact at European level. The Commission will make efforts in this sense.

2.0 KEY TECHNOLOGIES FOR DRIVING ASSISTANCE

We will now describe the state of development in Europe of a number of key technologies for driving assistance.

2.1 Adaptive Cruise Control (ACC)

ACC research has started in Europe very early during the Prometheus project (1986-1994). During these years, several European car manufacturers have experienced with a first generation of expensive scanning radar (mainly from Celsius). During these first years, the control of the distance was performed almost exclusively through throttle control without action on braking which was thought to be too risky.

These researches brought several companies to the development of radar and control systems for ACC. Besides Celsius, appeared ADC, Thomson-CSF (to become later Thales which formed the joint venture Autocruise together with TRW), Bosch and Siemens.

DaimlerChrysler was the first company in Europe to introduce ACC on a vehicle (the Class S) in 1999 with action on both throttle and brake (limited to 3m/s/s). Similar systems are now starting to appear on other European brands with similar performances. The limit on the braking capacity makes these systems comfort systems and not safety systems since in emergency braking, the driver has to take control. He remains entirely responsible for the vehicle.

All these systems now on the market have a range of 120 to 150 m and work rather well on highways with a headway which can usually be set manually between 1.0 and 2 sec. This headway is comfortable for the driver but in very high density traffic (where headway is often below 0.5 sec), it can lead to many cut-ins and can therefore become a dangerous feature. This

headway leads also to a decrease in throughput in very dense situation, if many cars are equipped. The ACC is turned off automatically when the speed is below a certain threshold (about 30 km/h) and hence is not usable in city environments.

Simulation research performed during the DIATS European project has also shown that, depending on the type of control algorithm implemented in the speed controller (and which is proprietary and hence usually unknown to the researchers), the stability of a string of ACC cars is not guaranteed. However, a mix of cars, some with ACC, may also decrease shock waves in dense situations, but this is still a research issue.

The research on longitudinal control is now focused on improvements of this basic ACC with better sensing of the scene ahead and laterally in order to allow operation in stop-&-go situation. One approach is to improve the radar with a better angular accuracy and a better range without using a mechanical scanning which is expensive. The other approach taken in particular by Siemens in the European project RadarNet, is to combine several radars to obtain these range and accuracy.

The most promising approach is however to combine radar with vision because the radar by itself is not aware of the road ahead (except in simple highway situations with very large curve radii) and hence cannot distinguish between an obstacle on the side or on the lane. This combination of sensing with radars (short range and long range) with lidar and with vision (mono and/or stereo) is the focus of the European Carsense Project.

2.2 Lane departure warning (including lane keeping assistance)
Lane departure warning and lane keeping has also started in Europe under the Prometheus Project with a number of operational prototypes presented at the end in 1994. All of these developments were based on the detection of lane markings or road sides through vision systems. The first systems used dedicated (and expensive) hardware but as soon as 1996, regular microcomputers had enough processing power to do this task.

The research has progressed in parallel (and often in cooperation) between industry and public research on both tasks: road detection and steering control. Several prototypes have been demonstrated since Prometheus, the most noticeable being the demonstrations by DaimlerChrysler (which included also ACC, obstacle avoidance and sign recognition) and the ARGO demonstration (http://millemiglia.ce.unipr.it/ARGO/english/index.html) by the University of Parma, Italy, which ran a vehicle through Italy in 1999.

Although lane departure warning could bring an improvement in the safety of vehicles (especially trucks and coaches), there are still discussions about the acceptance of such systems which do not bring any perceived immediate benefit in terms of comfort to the driver who might also be annoyed if the rate of false alarms is too high. The Rosetta project is looking closely at the introduction of these systems and how they could become mandatory for certain types of vehicles if we can demonstrate that the safety is improved (drivers might depend on them to continue driving while they are falling asleep….).

Lane keeping assistance is an even more complex situation with many safety issues, especially if it is coupled with ACC (we are then close to full driving automation even if the manufacturers insist this is only a comfort feature….). The technology is ripe for the introduction of this feature on well marked freeways with the availability of electric assisted steering and

inexpensive vision systems (as it has been demonstrated in Japan with the Nissan Cima), but the European car manufacturers seems to be quite reluctant to install such features on private cars and even on trucks (we will talk about platooning of trucks in the fully automated section).

However, there is one area where lane keeping is now an industrial product : it is for guided bus. This technique, which is in competition with mechanical guidance through a single rail imbedded in the ground (Ansaldo, Bombardier, Lohr) uses vision guidance developed by Matra and is commercialised by Irisbus on the Civis articulated bus. Two French cities (Clermont and Rouen) have already ordered such systems and many cities throughout the world are interested. This technique offers a cheaper alternative to light rail because of the lower cost of the infrastructure. A similar product is under development in the Netherlands by the APTS Consortium with the Phileas, a double articulated hybrid bus with lateral control through magnets imbedded in the road but also with longitudinal control, all developed by Frog Navigation Systems.

2.3 Side-obstacle warning systems (lane-change assistance)

Side warning and lane change assistant has been demonstrated on the VITA II demonstrator from DaimlerChrysler at the end of the Prometheus project. This demonstration included even full lane change automation and relied on a large number of CCD cameras.

Since then, the technology has moved towards simpler systems using mostly short range lateral radars but there is no system available on the market at this time. However, research is still very active in this field with several European projects dealing at least partly with this topic or with low speed urban driving (PROTECTOR, CARSENSE, RADARNET…)

2.4 Maneuvering aids for low-speed operation (parking assistance)

In 1989, VW presented the FUTURA, a car equipped with laser sensors which was able to park automatically. Since then, this topic has been a major research subject in the scientific community with many demonstrations. The research has mainly focused on the trajectory computation and the planning in the presence of obstacles. However, the main problem of the sensors to grasp the geometry of the car environment has been left to the industry. At the moment, only ultrasonic sensors are available at a cost acceptable for the automotive industry and these are now available on several makes and are moving from high-end products to middle ground ones. These sensors however, offer only a very limited assistance through audio or visual feedback of the distance to close obstacles.

The company IBEO which has worked on the Futura, has developed and advanced scanning laser which is aimed at low speed assistance and in particular Stop-&-Go and parking. The goal of this company, which has recently been bought by SICK, a leader of safety laser sensors for the industry, is to manufacture a low cost product for passenger cars. This is however a formidable task since the actual cost, in low quantities, is two orders of magnitude above an acceptable cost. IBEO works on this topic under the European project CARSENSE.

Some theoretical work has however been performed using 3D vision (stereo and moving camera) in the public research community (and in particular at INRIA) and the industry is now moving in this direction with new R&D project now under discussion. Some of this work is carried out also in the CARSENSE Project.

2.5 Forward vehicle collision warning systems

Although it seems that such systems would be easier to develop and cheaper than ACC systems, there are still almost no product of this type on the European market if we except the ultrasonic parking sensors. One inexpensive Israeli product (ControLaser 200) using a single beam laser has been put on the market in the late 1990's, mostly for truck application but it seems that it did not meet a strong demand. This is probably due to the fact that such system are not perceived by their users as bringing any added value: they consider that they drive safely and do not like to be reminded (especially if this is not true) that they drive too closely from the preceding vehicle.

On the other hand, the ACC is perceived a bringing a driving comfort which is worth the price. Therefore it seems that such systems can reach the market only through state or company policies.

2.6 Night vision enhancement systems

Night vision is actively researched by the European car manufacturers and suppliers. Several systems are now being tested. Two technologies are considered. One uses near infrared CCD camera associated with active IR lighting. The other uses a non-cooled far-infrared imager and does not need a special lighting. Both systems have advantages and drawbacks. Near infrared needs a special light and can be disturbed by similar cars coming in the other direction. The visibility is also limited in the distance. Far infrared cannot see cold objects such as a parked car which has not been running for a long time.

However, the biggest difficulty of both systems lies with the human-machine interface. The general approach is to display the image seen by the sensor either on a head-up display or on a screen on the dashboard (eventually shared with other functions). Here again, both displays have their advantages and drawbacks. A this time, no system is available on the market but industrial research is very active.

2.7 Intelligent Speed Adaptation (ISA)

Intelligent Speed Adaptation (ISA) is a concept actively researched in Europe. It actually means speed limitation but under a more acceptable term since many drivers (and hence car manufacturers) are strongly opposed to such limits.

The concept now studied in various projects at the European level as well as at national levels has basically three variants. The first one gives only a visual or audio warning if the speed limit is exceeded. This system, like the forward collision warning, is hard to sell to customers who perceive it as a bother without any comfort value. The second variant implies a haptic accelerator pedal which allows the driver to maintain the maximum allowed speed without looking at the speedometer. At any moment, there is a possibility to go above the speed limit by pressing the accelerator above the threshold given by the system. This approach which can be sold as a comfort system has the preference of car manufacturers. The last approach is to limit the speed to the official limit without any possibility of override.

All these systems are based either on a localisation through a navigation system where the maximum speed limit has been added by segments or on a local communication system with the infrastructure. This second system has the advantage of being more dynamic to take care of changing conditions (fog, rain, snow, road work, congestion, school hours…). A dynamic

system could also allow for the implementation of automatic traffic flow control through variable speed limits, as it is already done in UK and in the Netherlands with variable message signs.

2.8 Driver monitoring
Here again, driver monitoring is under active research although it may be hard to sell such a product to the general public. Several European projects have looked at this topic and the automotive suppliers have now operational systems close to marketing. Siemens in France has just been granted by the PREDIT the award for the best research for enhancing the safety on roads with their driver monitoring.

These systems are based essentially on the monitoring of the driver face through vision. A small CCD camera placed in or near the rear view mirror looks at the driver's head, sometimes with infrared illumination. The principle is to look at the blinking time and at the time during which the eyelids remain closed. Sometimes, this information is coupled with steering movements to improve the detection of sleepiness. The major problem remains the number of false alarms with respect to the number of missed detections. A high number (maybe as few as one per day of driving) can upset the driver, while missed detection can lead to unsafe operation.

However, as soon as the figures have reached an acceptable level, since the system can be fairly inexpensive, it can be made mandatory on commercial vehicles and might interest some drivers as a safety option.

2.9 Fully-automated driving.
Although one of the goals of the Prometheus project was to explore the possibility of fully automated driving on regular highways (and hence among manually driven cars) with the demonstration of the VITA II prototype from Daimler, since then, fully automate driving has taken a more realistic approach with dedicated applications. These applications concern the military domain (which we will not address here), trucks application and public transit applications.

Truck applications have been studied in two main directions : a fully automated one on dedicated lanes and the platoon concept with one driver for several trucks on regular infrastructure. The fist approach is illustrated by the CombiRoad project in the Netherlands and more recently with the ULS (Underground Logistic System), also in the Netherlands. The first project which used mechanical guidance and electric energy pickup to drive trailers has since then been (temporarily?) abandoned. The second project is now at the prototype stage in the Amsterdam region and should link the Flower market with a major train station and the Schiphol airport with fully autonomous electric shuttles for small containers.

The second approach for automated trucks is illustrated by the CHAUFFEUR project (now in its second funding phase by the IST Programme of the EU). In this approach, a leading truck, manually driven on a regular highway infrastructure, "pulls" a number of electronically coupled driverless trucks. The technique is based on a vision system which localises the previous truck through active targets. A communication is needed between the trucks to insure the stability of the platoon and prevent collisions in case of sudden braking. Demonstrations have been carried at the end of the first contract in 1999 and more work is now in progress to refine the techniques.

In public transit operations, several projects of fully autonomous road transportation systems are under way. The oldest one is the ParkShuttle from Frog Navigation Technologies which has started its operation at Schiphol airport in December 1997 and has been running continuously since then. The system consists of four electric vehicles with a capacity of 12 passengers which run inside a large long term parking on dedicated tracks. These tracks cross regular traffic and are not completely separated from pedestrian traffic. Collision avoidance is performed by a scanning laser from SICK. Guidance is performed using the Frog technology based on transponders in the ground and a specific antenna in the vehicle. Top speed is about 30 km/h. A similar system has been put in operation in Capelle, a suburb of Rotterdam to link a train station to a business park.

In Lausanne, a similar system (Serpentine) based on small electric shuttles (4 passengers standing) is now being put in place. Its operation is due to start in the summer 2001 along the Geneva lake on a pedestrian zone but also on a zone with private cars (with speed limit of 30 km/h).

The same technology is now put into the HOV, a mass transit system based on a multi-articulated hybrid bus running on a dedicated lane also developed in the Netherlands and due to start its operation in Eindhoven in 2003. This bus should be totally automated but with the supervision of an operator and should run at up to 80 km/h. It is guided by magnets and includes collision avoidance. This system is close to the Civis mass transit but includes longitudinal control making it a "fully automated system" even if there is an operator watching. In the case of Civis, the operator controls the speed in same fashion as for a light rail system.

The small automated shuttles are also studied by several other companies in Europe and it seems that Europe could lead the rest of the world with this technique. A large European project called CyberCars (www.cybercars.org) due to start in the summer 2001 funded by IST and EESD, is going to improve the technologies involved and study the conditions for a large introduction of these systems in European cities.

LIST OF EUROPEAN PROJECTS ON DRIVING ASSISTANCE

EUROPEAN PROGRAMS

Table A.1 4th Framework Programme

Project name	Short summary	
TABASCO Telematics Applications in Bavaria, Scotland and others	The TABASCO project validated multi-modal information and control system implemented in cities and in their surrounding regions and assessed the integration of these systems to produce a more efficient transport systems as a whole. The main telematics systems demonstrated are control strategies and systems for traffic management, public transport traveller and park&ride information, incident warning, interconnection of traffic information and control centres.	ICC, Mr. Ian Catling, UK, 100613.3137@ compuserve. coa City and regional councils, BMW, DERA, GEVAS. ISIS, Microsense, MVA, MVV, Nederland Haarlem, Oscar Faber, SERCO, STERIA, TCSU etc.
UDC Urban Drive Control	The intention behind this project is to integrate environment and city management with individual drivers interests, by combining remote driving speed recommendations with autonomous longitudinal control of vehicles. The objective is to integrate traffic management and vehicle longitudinal control. It will use Short Range Communication technology transmitting driving speed recommendations via road side beacons to vehicles equipped with Autonomous Cruise Control	TÜV Rheinland. Mr. Orta Hofman, Cologn, Germany, o.hofman@tuev-rheinland.de, FIAT, PSA, Jaguar, ADC, City o f Turin, Mizar, Renault Thomson, Lucas

VASCO Vehicle ATT Demonstrations, Evaluation and Monitoring on a European Corridor Uniting Member States	The main objective of VASCO is to validate the Dedicated Short-Range Communication proposed for standardisation in Europe as a suitable technology to support road transport traffic telematic applications. Cases include Automatic/Electronic Fee Collection, Access Control, Traffic and travel information, Dynamic Route Guidance and others	Aachen University RWTH, Dr. Rokitanski, Germany, al @commets.rwth-aachen.de BOSCH, CMG, ISIS, GR0NER, Micro Design, TÜV, Siemens, CEGELEC, Combitech (SAAB), CS ROUTE, Alenia Marconi, TU Delft, Brisa, Renault., Thomson-CSF

TELSCAN	The project's objective is to ensure that all ATT applications (in the 4th framework programme) take into account the needs of the elderly and disabled	University of Aristotle Thessalaniki, Dr. A. Naniapoulos, Greece TRD, HUSAT, NTUA, TNO,IAT/IAO, VTI, LUND, INRETS,UTL Cranfield Traffic Solutions
AHSEA/ADASE	Advanced Driver Systems in Europe. The main activities are (i) to bring all stakeholders of transport and mobility together to harmonize and initiate activities in the field of ADA systems, (ii) to harmonize European research activities in the field of ADA systems, and (iii) to define functional requirements and system architecture for key ADA technologies.	DaimlerChrysler, Mr. B. Ulcer, Germany Berthold.ulmer@daimlerchrysler.com, BMW, CRF, Renault, Volkswagen, Rijkwaterstaat, Cofi Route, RAC

RESPONSE	Telematics Based Driver Assistance Systems are currently under development. Future Driver Assistance Systems may control the driving of the car to an extent where the driver is switched off uncertain traffic situations and the control of the car is taken over by the systems. RESPONSE pays attention to a number of questions beyond their technical feasibility, like consumer perspectives, dependability of the systems, impact of existing rules and legal considerations	TÜV Rheinlalid e.V. , Dr. Becker, Germany, beckers@tuev-rheinland.de VOLVO, BMW, BOSCH, Daimler, Benz FIAT, FORD, Peugeot, ITT, Jaguar, Renault, VITA, ,MIRA, Thomson, TRL Volkswagen
CONVERGE Telematics Sector Consensus and Support	The Transport Sector of the Telematics Applications Programme includes over seventy development projects, covering all transport modes in all European countries. In CONVERGE attention is paid to technical co-ordination, to ensure that the results are operable in common and valid at the European level and that key standards emerge from them,	ERTICO, Mr P. Kompfrer, Brussels, Belgium, p.kompfrenr@mail.ertico.com
DIATS Deployment of interurban ATT test scenarios	Identification of options currently available and likely to become available in the short and medium term for implementing "co-operative driving", based upon ATT systems for motorway type roads. -Development of scenarios of "highest potential impact" for each of the systems identified. -Identification of the elements needed to successfully deploy these ATT measures in field tests, and create awareness of the potential of this area of ATT.	University of Southampton, Prof. M. McDonald, UK. mm7@soton.ac.uk
AUSIAS ATT in urban sites with integration and standardisation	The main objective of AUSIAS is to demonstrate on a large scale and under real conditions, how Advanced Transport Telematics can help European cities to reduce congestion, improve traffic management and provide the means for a sustainable socio-economic improvement. The project rests on three strategic principles: integration, standardisation and new technologies.	Mr. Antonio Marques, Electronic Traffic, S.A., Spain, Margues_etra@vlc.servicom.es

CHAUFFEUR	CHAUFFEUR is aimed at developing systems, which will increase the density of freight traffic and enable better use to be made of existing roads. The project has two stages. The first stage will have two Trucks linked automatically. In the second stage this concept will be extended to "platooning" and "Automated Platooning/Automated Driving" concept where several trucks are linked electronically.	DaimlerBenz, Mr. M. Schulze, Stuttgart,, Schulzem@dbag.stg.dalmlerbenz.com, Fiat, Centro studi sui Sistemi di Transpono IVECO, TÜV, Robert Bosch, RWS
COSMOS Congestion Management strategies and methods in urban sites	The central objective of COSMOS is to build and verify demonstrators for congestion and incident management in the context of urban network signal control.	MVA Consulting CST, Heuseh Boesefeldt, TRL, Siemens
DACCORD Development and Application of Co-ordinated Control of Corridors	The main objective of the D'ACCORD project is to design, implement and validate a practical Dynamic Traffic Management System for integrated and co-ordinated control of inter-urban motorway corridors, An additional objective is to develop an open system architecture for inter-urban traffic management	Hague Consulting Group, The Hague, Netherlands cemro Studi Sui Sistemi d Transpon, RWS: TNO, INRETS
IN-RESPONSE IncidentResponse with on-line Innovative Sensing	IN RESPONSE will develop and validate integrated detection and response strategies, based on innovative sensing. Incident detection and response will be improved across rapidly changing traffic conditions.	TrutH, Prof. Stephanedes. yargos@itel.gr Alcatel, SINTEF, RWS, TNO

PROMISE Personal Mobile Traveller and Traffic Information Service	The objective of PROMISE is to provide travellers with easy access to a multi-modal travel and traffic information service during their whole journey. The consortium will create a mobile multi-modal traveller information system for Europe-wide deployment.	Nokia, Mr. T. Ojola. Tommi.ogala@nmp.nokia.com Volvo, British Telecom, IBM, BMW, RWS, Renault.
EUROSPIN, European Seamless Passenger Information network	The main objective of EUROSPIN is to develop and demonstrate seamless public travel information services across transport modes and geographical boundaries.	WS Atkins; Mr. M. Cummings, Epsom, Surrey, England. mcummings @ wsatkins. co. UK
EPISODE, European Preoperational and Implementation survey on further development and evaluation of RDS/TMC	The EPISODE project is assessing the research and implementation projects in the EC 4V, framework programme with any TMC (Traffic Message Channel) components at the European and National levels.	Mr. Dietmar Kopitz. EBU/UER, Switzerland. kopitz@ebu.ch
COMETA, Commercial Vehicle Electronic and Telematic Application	Increasing numbers of ON-Board systems are being offered by the market or imposed by authorities. The objective of COMETA is to define and design modules for on-board functions and make efficient interfacing possible within an overall transport telematic system	AFT IFTIM IPTL, Mr. Miguel Solis. France, msolis@easynet.fr

ADEPT 11, Automatic Debiting and Electronic Payment for Transport	The objective of the ADEPT 1I project is to develop and test interoperable open payment systems to meet the requirements of a number of transport services. It has particular reference to issues associated with the interface between inter-urban and urban road networks	University of New Newcastle upon Tyne Transpon Operations Research Group Mr. Phillip Blythe, UK p.t.blythe@newcastle.ac.uk or n.t.thorpe@newcastle.ac.uk
MOVE-IT Motorways operators validate electronic fee collection for interoperable transport	In the area of electronic fee collection (EFC) for motorway tolling, one of the main issues concerns contractual interoperability. It is necessary to achieve consensus on identifying and putting in place the legislative, institutional and commercial bases for interoperable systems. In the MOVE-IT project European motorway operators are trying to overcome some of the obstacles to doing that. systems.	Dutch Ministry of Transport, Mr Van Wijk, Netherlands, dik.vanwijk@dgb.nninvanw.nl partners European Motorway Operators
ADVICE Advanced Vehicle Classification and enforcement	THE ADVICE project focuses on EFC and aims to develop and test automatic vehicle classification and enforcement systems and to produce common European guidelines for the specification of such system. The purpose is to make enforcement systems interoperable and facilitate cross border violators prosecution.	TRL Mr. Perrett, UK. kenp@t.trl.co.uk GEC-Marconi, TÜV etc

MASTER Managing speeds of traffic on European roads	The aim of the project MASTER is to provide recommendations for speed management strategies and policies and develop guidelines for the development of innovative speed management tools, The approach is comprehensive, in addition to safety it takes into account also other factors which are relevant in the definition of adequate speed management policies. The main objectives of the project are: (i) Development of speed management strategies, and (ii) Development of recommendations for speed management policies.	VTT, Mr. Veli Pekka Kallberg, Finnland TNO, LUND university, etc
AC ASSIST/ROADSTER Anti Collision Autonomous Support and Safety Intervention System	The AC ASSIST project will address the needs of drivers for systems to support the driving task, specifically in critical situations. Its focus is on the validation of autonomous systems capable of providing anti-collision assistance and vehicle control. The aim is to demonstrate warning and intervention functions that provide Collision Avoidance along the longitudinal axis of the vehicle	Jaguar Cars, Mr. N. Clarke. Great Britain. Nclarke2@Ford.con Volvo, Fiat, Centro Studi sui sistemi di Transparto, Renault. Rover, CTI Lucas Applied technology
SAVE System for effective Assessment of driver state and vehicle control in Emergency situations	The aim of this project is to develop an integrated system, a "SAVE" unit that will detect driver state and undertake Emergency handling in real time, prior to and during an Emergency situation. This will be achieved by instant detection of driver impairment and shift of car status to automatic driving mode, so as to control it effectively and safely.	TRD, Athens branch, Dr. A. Bekiaris Greece, trnspcon@athena.compulink.gr INRETS, RWS, TNO, Philips, Renault, Siemens, VTI

LACOS Lateral Control Support	The LACOS project will address drivers needs for assistance systems, in particular in critical situations. Lateral manoeuvres have been evidenced as some of the more critical that drivers have to make. The project will accordingly focus on collisions along the lateral axis of the vehicle due to lane change and departure from a road, and the combination of the two tasks and will validate anti collision systems that deal with the manoeuvres	Centra Ricerce FIAT, Paola Carrea, Italy, p.carrea@crf.it TÜV, Renault, Volkswagen, centro Studi sui Sistemi di Transporto
INARTE Integration of Navigation and Anticollision for Rural Traffic Environment	Integration of Navigation and Anticollision for Rural Traffic Environment is being investigated. Different technologies, like collision warning and navigation systems are combined.	Centra Ricerce FIAT, A. Saroldi, Saraldi@CRF.IT , Italy TÜV, Renault, Volkswagen, Siemens, Navtech, VTI, Fraunhofer, TNO

Table A.1 5th Framework Projects

Project name	Short summary	Partners
CARSENSE Sensing of Car Environment at Low Speed Driving	Development of new sensor and the fusion algorithms for a better perception of the car environment	BMW, Fiat (CRF), Renault, TRW, IBEO, Thales, Jena-Optronics, INRIA, INRETS, LCPC, ENSMP
CHAMELEON Pre-crash Application All Around The Vehicle	Main objective of CHAMELEON project, is to support, to guide and to validate the development of a pre-crash sensorial system necessary for near impending crash detection all around the vehicle and in all scenarios. Under this point of view, there are several objectives to achieve this goal.	EICAS Automazione S.p.a., Saabtech Electronics Ab, Thales, Technische Hochschule Aachen, Peugeot Citroen Automobiles Sa, Ramot (Tel-Aviv), Porsche, Israel Aircraft Industries Ltd, Temic Telefunken Microelectronic Gmbh, Renault, Volvo, Obeo, Centro Studi Sui Sistemi di Transporto Spa.
CHAUFFEUR II Promote Chauffeur II	A continuation of CHAUFFEUR. The Tow-bar technology developed previously will be improved into a saleable product. The idea is to provide a "chauffeur assistant" able to follow any vehicle. A fully operable platoon of trucks will also be realised including manoeuvres. Cost analysis and performance evaluations will be performed on the various systems.	DaimlerChrysler, Fiat (CRF), Renault VI, PVW&A, Bosch, ZF, Centro Studi sui Sistemi di Transporto, Benz Consult

NEXTMAP Next MAP for transport telematic applications	NextMap is a research project to define, prototype and evaluate the content of digital map data bases required for future in-vehicle ITS applications, in particular, Advanced Driver Assistance Systems (ADAS). ADAS applications support the driver in driving safely, comfortably and economically and include information, warning and control systems. NextMap will also propose and submit to ISO standardisation an extension to GDF reflecting the requirements needed by these applications.	Navtech, Tele Atlas, BMW, Fiat (CRF), DaimlerChrysler, Jaguar, Renault, ERTICO
PROTECTOR Preventive Safety For Un-protected Road User	The general objective is the improvement of safety of vulnerable citizens (pedestrian, cyclists, motorcyclists) in urban and rural areas, based on the interaction of enhanced autonomous on-vehicle sensors (based on laser, microwave and computer vision technologies) with co-operative means carried by the vulnerable road users (transponders, microwave/optical reflectors, etc.). The development, evaluation and validation of the autonomous and/or co-operative detection means, in real environment or in an "ad hoc" established test site for the most critical scenarios are the operative objective of the project, both at automobile and commercial vehicle level.	Siemens, DaimlerChrysler AG, Rheinisch-Westfaelisch Technische Hochschule, AachenIsrael Aircraft Industries Ltd, Universita degli Studi di Pavia, Man Nutzfahrzeuge Aktiengesellschaft, TUEV Kraftfahrt GmbH, Ramot (Tel-Aviv) University for Applied Research and Industrial Development Ltd., Ibeo Lasertechnik Hipp KG, Centro Studi sui Sistemi di Transporto Spa
RADARNET Multifunctional Automotive Radar Network	RadarNet is a path-breaking European project targeted on the development of a new, powerful, multifunctional radar network for automotive use. It aims at the development of a new 77 GHz gallium arsenide MMIC based chipset for FMCW radar and its integration in a radar network on board of the vehicle.	Siemens, Infineon, Univ. Of Birmingham, Institut Plytechnique de Toulouse, Technical Univ. Of Hamburg, BMW, Fiat (CRF), DaimlerChrysler, Volvo, Jaguar.
ROADSENSE	ROADSENSE supports European motor vehicles manufacturers in developing codes of practice in the field of vehicle safety and human-vehicle interaction. The initiative addresses the need to reduce the number of deaths and injured persons on European roads.	Jaguar, Fiat (CRF), Porsche, University Clermont-Fd, Cranfield University, TNO, Univ. of Compiègne.

Table A.2 EUREKA project

Project Name	Short Summary	Companies Involved
Transport		
CALLIOPE † †	THE PROECT IS IN 2 PARTS: A SPEECH SYNTHESIS VOICE OUT PUT EASED ON THE `TEXT TO SPEECHÅf.PROCESS USED FOR TRAFFIC ANNOUNCEMENTS AND A SPEECH RECOGNITION VOICE INPUT USED IN THE CONTROL SYSTEM.	Jean Michel Depresle - Paris, France **SAGEM-SIEGE SOCIAL**
CITA †	DEVELOPMENT OF AN ADVANCED DEMAND-RESPONSIVE DISPATCHING SYSTEM THAT OFFERS AN EFFECTVE SOLUTION FOR HANDLING SMALL RURAL PUBLIC TRANSPORT COMPANIES OR NETWORKS	Carlos Roca Garcia - Gefale, Spain ENA TRAFICO SA form telecom

EURAXIAT † †	DEVELOPMENT OF DIGITAL EQUIPMENT WHICH WILL CONSIST OF A DEVICE USING A CARD WHICH CAN BE FITTED ON BOARD TRANSPORT VEHICLES TO AUTOMATICALLY INDICATE AND RECORD DATA PERTAINING TO THEIR MOVEMENTS AND TIME IN SERVICE.	Christian Morel - Brest, France † THOMSON CSF BERENCISE
EUROPOLIS †	DEVELOPMENT AND TEST OF AN IMPROVED AND NEW INTEGRATED CONTROL SYSTEM FOR INTER URBAN/URBAN ACCESS CORRIDORS BASED UPON SIGNAL AND VARIABLE MESSAGE SIGN PRODUCTS	Jorge Subirana - Barce/ona, S~ **ABENGOA SAINCO TRAFICO** **S.A.**
PLEETS (FEA) † †	TRANSNATIONAL FOCUS GROUP COMMITTED TO RESEARCH PROJECTS TO ACHEVE PRACTICAL SOLUTIONS FOR SUSTAINABLE TRANSPORT SYSTEMS WITH MINIMUM ENVIRONMENTAL IMPACT AND MAXIMUM USER ACCEPTANCE THROUGH HYBRID VEHICLE AND TELEMATICS TECHNOLOGY.	Paul A.G. Bromby - Nuneaton, United Kingdom MIRA THE MOTOR INDUSTRY **RESEARCH ASSOCIATION**

MACADAM-STAR †	THE PURPOSE OF THIS PROJECT IS THE PRE-DEVELOPMENT OF CAR EQUIPMENT THAT SHOULD HELP THE DRIVER TO CONTROL RELATIVE SPEEDS AND DISTANCES WITH VEHICLES AHEAD.	Gerard Vassa/ - Velly Villacoublay, France PSA PEUGEOT CITROEN
PIV † †	DEVELOPMENT OF SMALL, LIGHTWEIGHT, ENVIRONMENTALLY-FRENDLY VEHICLES FOR PERSONAL TRANSPORTATION, SERVING AS A PARTLAL REPLACEMENT FOR NORMAL CARS, IMPORTANT CONSIDERATIONS IN VEW OF NEW REGULATIONS COVERING SUCH VEHICLES.	Chrlstoph Rust - Graz, Austria STEYR DAIMLER PUCH FAHRZEUGTECCHNIK GMSI
PROMETHEUS † †	CREATION OF CONCEPTS AND SOLUTIONS WHICH WILL POINT THE WAY TO A ROAD TRAFFIC SYSTEM WITH GREATER EFFICENCY ECONOMY AND WITH REDUCED IMPACT ON THE ENVIRONMENT COMBINED WITH ADEGREE OF UNPRECEDENTED SAFETY	Walter Scholl - Stuttgart, Germany DAIMLER BENZ AG

ROADACOM † †	INTEGRATED SYSTEM FOR ON-BOARD ELECTRONIC DATA COLIECTION AND PROCESSING AND BI- DIRECTIONAL EXCHANGE OF DATA BETWEEN COMMERCIAL VEHICLES AND THEIR HOME BASE _ TO IMPROVE ROAD TRANSPORT EFFICENCY	Bert Duursma - Veldhoven, Th Nederlands SIMAC SYSTEMS BV Francisco Palazon - Majadhon
SBUS(DEF)	STARTING FROM AN ADVANCED VEHICLE MONITORING, SBUS SEARCHES FOR A REAL TIME' STATISTIC INTEGRATION OF ALL INFORMATION SYSTEMS IN THE COMPANY. IT IS AN ITS PROJECT IN THE FELD OF ADVANCED PUBLIC TRANSPORT SYSTEMS (APTS).	Francisco Palazon-Majadhonda Spain TEKIA CONSULTORES TECHNOLOGICS

TRAPRIO	USE OF LOW FREQUENCY TAG TRANSPONDER, COMPUTER, RADIO COMMUNICATION AND SATELLITE TECHNOLOGY FOR IMPROVEMENTS ON EMERGENCY VEHICLE OPERATION (POLICE CARS AND AMBULANCES IN PARTICULAR) AND IMPROVEMENTS ON PUBLIC TRANSPORT SERVICES.	Flemming Lohmann Jensen -
†		Gentofe, Denmark
†		TRAFFIC SUPPERVISION
†		SYSTEMS APS

Information Technology:

CHiPPER++	THE AIM IS TO CREATE A STATE-OF-THE-ART SMART CARD CONCEPT THAT WILL BE UNIQUE IN THAT IT WILL INTEGRATE A MULTITUDE OF DIFFERENT CARD ISSUERS, SERVICE PROVIDERS AND CARD ACCEPTING	Michel van Wissen - Hoofddorp,
†		The Netherlands
†	AGENCES INTO A SINGLE OPEN ELECTRONIC INFRASTRUCTURE.	CHIPPER NL. VOF
†		

OLTASTIC	IMPROVEMENT OF TRAFFIC SAFETY/JOURNEY TIMES ENVIRONMENTAL IMPACT THROUGH CONSTRUCTION OF ANALYSIS SYSTEM FOR TRAFFIC INFORMATION/CONTROL BASED ON INTELLIGENT SIGNAL ANALYSIS ON	Thomas Ekdahl - Mariefred,
†		Sweden
†	SITE AND REAL-TIME DATA TRANSFER TO A CENTRAL UNIT	ALLOG AB
†		
†		

Communication :

DAB(iMP) † †	PHASE 1: DEVELOPMENT OF A EUROPEAN TECHNICAL STANDARD FOR DIGITAL AUDIO BROADCASTING. PHASE 11: FINAL SYSTEM STANDARDIS ATION AND DESIGN, SYSTEM VERIFICATION AND INVESTIGATION OF IMPLEMENTATION ASPECTS.	Egon Meier Engelen - Koeln, Gemmany DLR ROJEKTTRAEGER INFORMATIONSTECHNIK, DEUTCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV
INNOSAT † †	THE PROJECT AIMS TO DEVELOP AND IMPLEMENT AN ADVANCED SYSTEM OF COMMUNICATION AND MANAGEMENT FOR FLEETS SUCH AS: TAXI (RADIO TAXIS), COURRER, TRAIN, METROPOLITAN BUS, HEALTHCARE AND OTHER PUBLIC SERVICES.	Valentin Murillo - Pamplona, Spain SISTELEC ELECTRONICA SL

	Regional research programmes	
Project name	Short summary	Companies involved
MOTIV: Mobility and Transport in Intermodal TRaffic	MOTIV has two research programmes, namely • Mobility in Urban Areas, with projects like Integrated Mobility and Transport data Network, Personal Travel Assistance and Simulation Tools • Safe Roads. This programme has close links to ADA systems. Projects include Turn-off and Lane-change Assistance, Adaptive Cruise Control, Vehicle-Vehicle Communication, Driver Assistance Strategies and Man-Machine Interactions	MOTlVBuro, WalterScholl Walter.Sholl@idnet.de, Germanywww.tuev-rheinland.de/tsu/bvt/motiv BMW, DaimlerChrysler, IBM, Opel, Man, Philips, Robert Bosh, Siemens, TERAGON, VDO, Volkswagen
VIKING	Northern Europe's traffic is often disrupted by harsh weather conditions. To better manage the impact of weather on traffic, and to take advantage of new technologies to case other traffic-related problems, the VIKING project co-ordinates national and bi-lateral traffic management schemes, and implementation of Intelligent Transport Systems (ITS) in Scandinavia (Denmark, Sweden, Finland and Norway) and five regions in northern Germany. Different subprojects have been defined (between brackets the facilitating country): Traffic Monitoring (Finland), Information Networks (Denmark), Traffic Management Tools (Sweden), Traffic Management service (Germany), Fee Collection (Norway), Project Management (Sweden)	Christer Karlsson, vägverket Borlange, Sweden christer.karlsson@vv.se.www.viking.mineline.se various road directorates and ministries of Denmark, Finland Germany, Norway and Sweden

PREDIT Programme de Recherche et Innovation dans les Transports terrestres	This national programme in France (1996 until 2000) support actions on research about land Transportation. The projects depend on 4 French ministries and 2 agencies. The programme covers activities of research, development and experimentation in the areas of rail and road transport, public transport of freight and persons and problems of transport organisation in urban areas.	4 French ministries, 2 agencies, French industry and service providers. http://demo.3ct.com/predit/wwwroot/01/home.htm
La route automatisee (LARA)	A national research programme in France, focusing on driving automation of all road transport modes	INRETS, INRIA, LCPC, ENSMP, ENPC, ENST www.lara.prd.fr
Foresight Vehicle Initiative	A national programme in the United Kingdom, stimulating technologies for use in mass-market vehicle in 2020. Keywords are clean efficient, lightweight, telematic, intelligent, and lean. 'The foresight Vehicle initiative' programme is an umbrella for Government supported automotive technology programmes in the UK. The programme brings together industry, supplier, research, technology, user, public and government organisations. Projects include: Aerostable Carbon Car, Hybrid electric realised off-road, Millimetre wave antennas for future vehicles, Road Origin and direction attained by radar, Electronics, Composites, Camera technologies, Supply chains, Light weight cars, etc.	Dr Mike Sporton, Foresig, Co-ordinator,GrenTek Ltd, Grennville House, http://www.lboro.ac.uk /Alumni/fiboct98/foresigh.htm

Autonomous Driving	The aim of this project is to automate the durability tests of ordinary mass-produced cars on a special course. This approach is motivated by the fact that after several years of driving, human drivers can be affected by extreme strain. This application also provides a first step to obtain an electronic co-pilot for all traffic situations. Thus, a concept is developed which include a test vehicle being driven by a robot observing its surroundings to avoid obstacles, and overruling the vehicle control by the electronic copilot in case of an emergency.	Mr. H. Weissler, Volkswagen AG, Group Research, Environmental and Transport, Wolfsburg, Gernaany Robert Bosch, Kasprich-lBEO, Witt. SICAN f&E, TU Braunschweig
Intelligent Speed Adaptation † †	The aim of this Dutch research project is to test the application of Intelligent Speed Adaptation in a residential area in the Netherlands. In this pilot a limited number of vehicles is equipped with ISA. The project assesses both technical as well as social feasibility of ISA. A similar project is currently running in Sweden	Rijkswaterstaat-Transport Research Centre (AVV), P.O. Box 1031, 3000 BA Rotterdam the Netherlands.
PAROTO	Drivers assistance and filtering of information in difficult environments. The project has a strong focus on human-machine interfaces and ergonomy.	SAGEM, ONERA, TEAM, INRETS (France)

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